Ph313, Week Two, Lecture Notes

Author: 

The title of this course is *Energy Alternatives*

Let's first precisely define what it means. Take the Webster Definition and look up *Alternative.* We find:

Adjective:

1: offering or expressing a choice <several *alternative* plans>

2: different from the usual or conventional: as

- a: existing or functioning outside the established cultural, social, or economic system <an *alternative* newspaper> <*alternative* lifestyles>

  b: of, relating to, or being rock music that is regarded as an alternative to conventional rock and is typically influenced by punk rock, hard rock, hip-hop, or folk music

  c: of or relating to alternative medicine <*alternative* therapies>

Noun:

1 a: a proposition or situation offering a choice between two or more things only one of which may be chosen

  b: an opportunity for deciding between two or more courses or propositions

2 a: one of two or more things, courses, or propositions to be chosen

- b: something which can be chosen instead <the only *alternative* to intervention>

3: alternative rock music

Clearly, the highlighted items are the most appropriate for *Energy Alternatives.*
In short: generally, the term *Energy Alternatives* refers to resources that can be chosen instead of the established methods of energy production.

Traditional fuels & resources;

- **Coal (since early 1700s);**
- **Oil (since mid-XIX Century);**
- **Natural gas (as above);**
- **Hydropower (many millennia!);**
- **Nuclear fission (since 1950s).**

Extracting energy from the first three items in the list involves burning

Energy alternatives:

- **Solar energy (direct usage);**
- **Wind (solar, too! – indirectly);**
- **Bio-fuels (again, solar!);**
- **Hydropower (one more solar!);**
- **Nuclear (returning to favors);**
- **Ocean waves;**
- **Tides;**
- **Geothermal energy;**
- **……. (probably a few items can be still added).**

The next page is meant to entertain you.
This course is about "Energy Alternatives", right? However, we will begin with talking about *conventional methods of power generation, involving burning of fossil fuels*. **Why?**

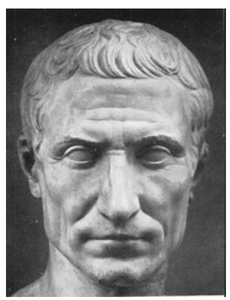
- **Because you may be a <u>friend</u> of fossil fuel burning (global warming is a hoax! – who said that?) and think of "energy alternatives" as of an obsession of the "green radicals"; or**
- **Because you may be a friend of the "green energy", and treat the smelly fossil fuel-burning facilities as a <u>foe</u>.**

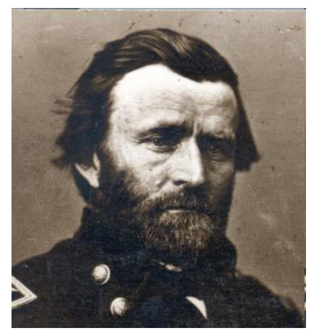
No matter which group you belong to, you should know much about the "smelly" methods as well as about the "green methods". Why?

“Traditional” methods – we don’t like them (why?).
Think <u>green</u>:
They are our enemy! We want to eliminate it!

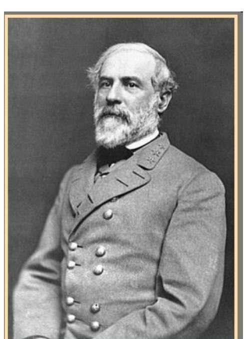
“Traditional” methods – we DO like them (why?).
Think green(backs)$$$$: They work well, global warming is a hoax!

Well – and keep in mind what the greatest military leaders in history always used to say:



<u>Rule Number One for a victorious campaign</u>:



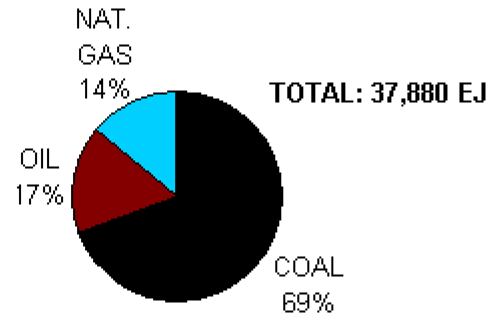
73. Three Generals: Dwight D. Eisenhower, Omar N. Bradley and George S. Patten (NA)

Know your enemy! Learn about all its weaknesses and <u>strengths!</u>

Fossil fuels – basic facts and numbers:

Major – global resources:

- **Coal:** 997,748 million short tons (4,416 BBOE; 2005)
- **Oil:** 1,119 to 1,317 billion barrels (2005-2007)
- **Natural gas:** 6,183 - 6,381 trillion cubic feet (1,161 BBOE; 2005-2007)



Minor (or not yet fully exploited):

- **Tar sands** (contain "bitumen", a form of heavy oil): 1.7 trillion(!) BBOE;
- **Oil shales** (as above) 411 gigatons, or 2.8 to 3.3 trillion(!) BBOE;
- **Methane hydride –** (resources unknown, by some believed very large).

BBOE = Billion Barrels of Oil Equivalent

Energy conversion – a convenient program

Flows (daily production) during 2006

Oil: 84 million barrels per day;
Gas: 19 million barrels oil equivalent per day {MBOED}
Coal: 29 million barrels oil equivalent per day MBOED

How long will those resources last?

Years of production left, due the most optimistic reserve estimates (Oil & Gas Journal, World Oil)

Oil: 43 years

Natural Gas: 167 years

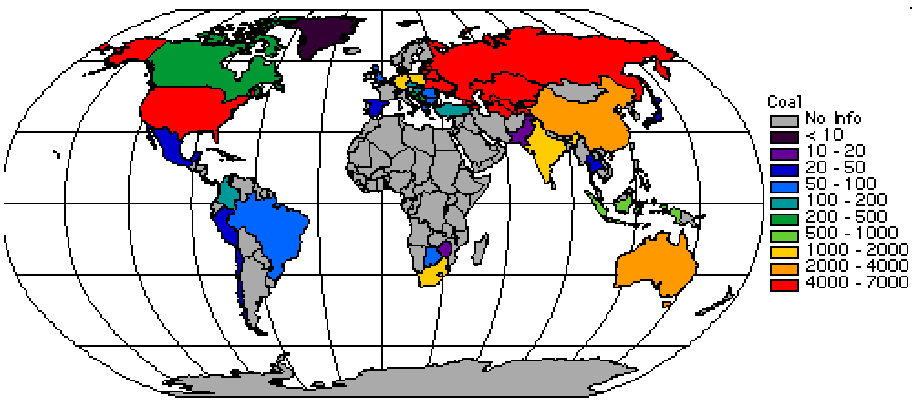
Coal: 417 years

(FYI, not for any longer discussion in class)

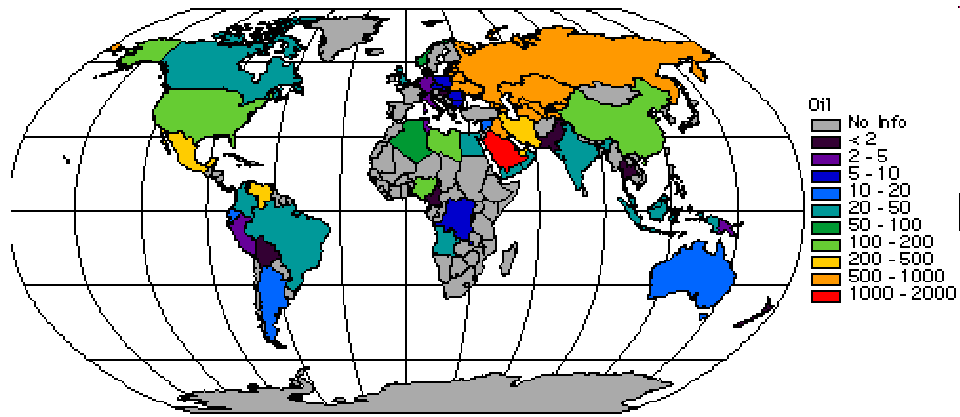
The distribution of coal, oil and gas deposits by country, shown using colors

Red – largest resources; Black – smallest resources

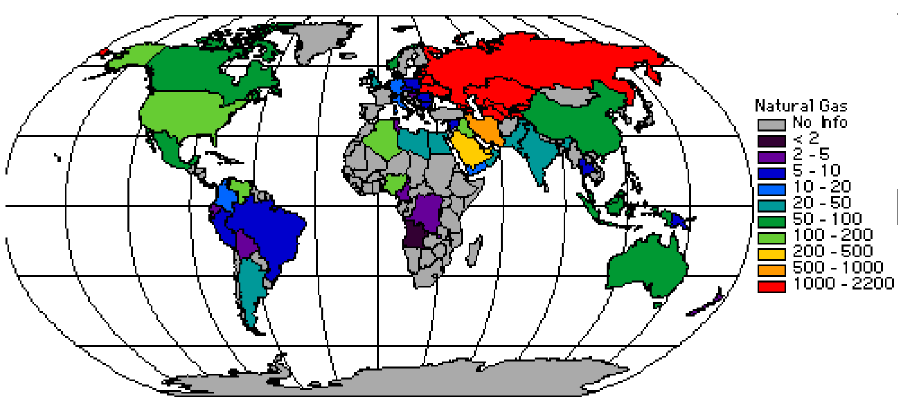
COAL:



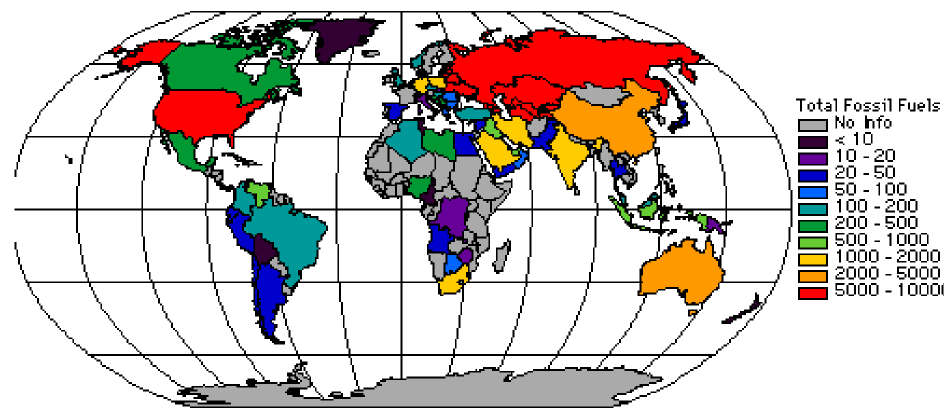
OIL:



GAS:



TOTAL:



How are fossil fuels used? We just burn them, that's all! But in many different ways:

- **Simple combustion;**

- **To generate heat needed in many types of industrial processes, e.g., smelting, chemical synthesis, ….**


- **In *heat engines*, using various types of combustion, propelling cars, trucks, railway engines, planes, ships, …**


- **In *heat engines*, to generate mechanical energy, and then electric power;**

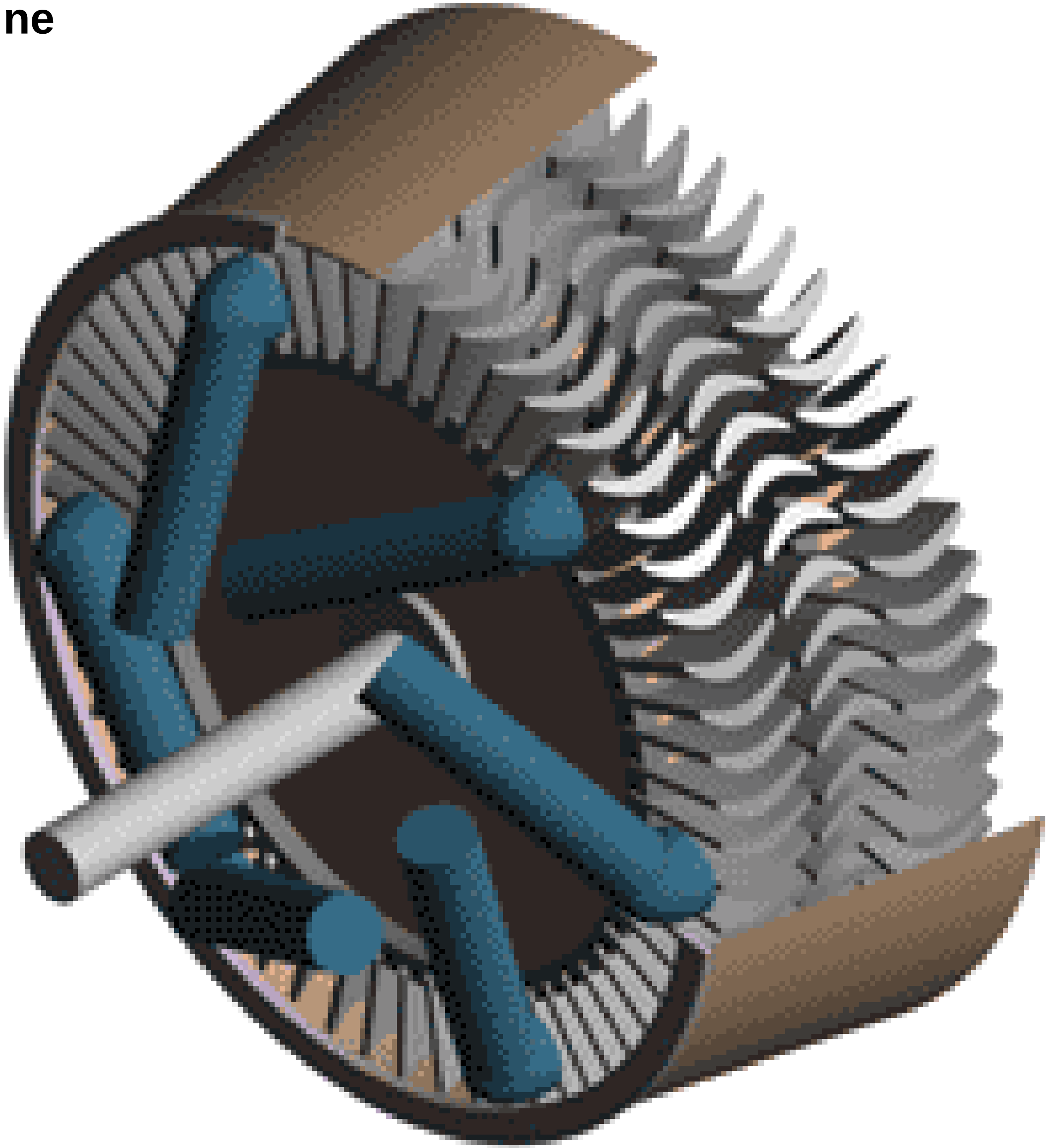

The next few pages will be about heat engines. First, about types of heat engines – but there are zillions of them, so we will only pay some attention to the first-ever steam engine built in 1705, knowa as the "Newcomen Atmospheric Engine" – because in Homework One you will be asked for calculating the efficiency of such a monster.

An animated picture explaining the phases of the work-cycle of the Newcomen machine, as well as of twenty other different types of heat engines, is shown in this Web page.

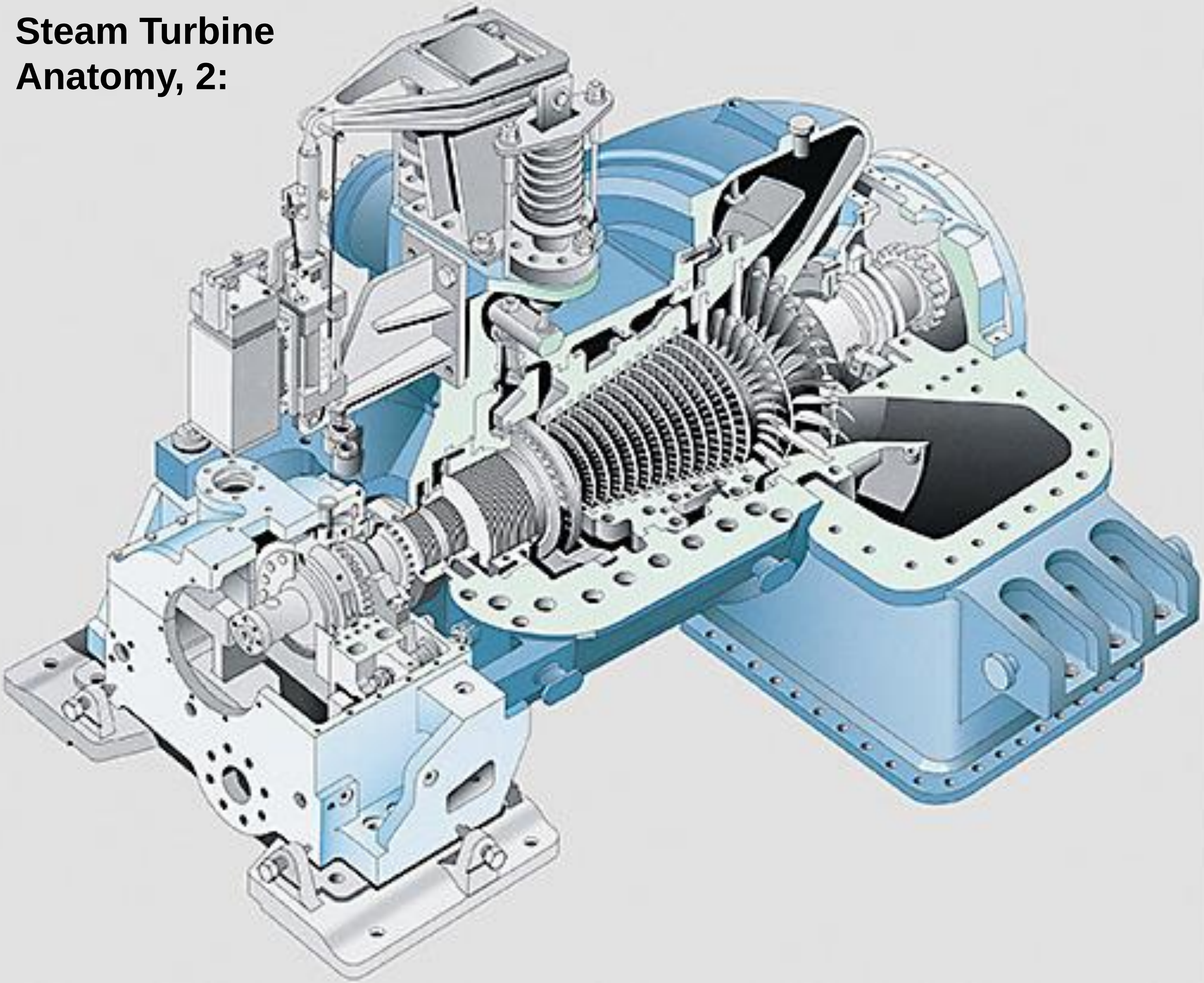
The only other heat engine types we will pay attention to this week are turbines, primarily steam turbines, which are used for generating more than 50% of all electric power globally used – and natural gas turbines, which use fossil fuel, but of all heat engine types they are perhaps the type "friendlest to the environment".

Here is a link **to a nice and instructive 6-minute Youtube video about steam turbines**

Steam Turbine Anatomy:



Steam Turbine Anatomy, 2:




They are huge monsters…

Here is an interesting piece of information from September 2016, about the largest steam turbines ever made, called Arabelle. Two of them are currently being installed in Great Britain, each of the power of 1,770 MW – since the power of the engine of a compact automobile is currently of the order of 100 kW, or 0.1 MW, it means that each of these supermonsters will yield the power of nearly EIGHTEEN THOUSAND OF COMPACT CAR ENGINES COMBINED!! Hard to believe....

A link to another Web site on Arabelle turbines.

As you see, heat (or, rather thermal energy) from steam can be transformed to mechanical energy. And there is a range of other heat engine types that can be "employed" to perform many useful tasks (e.g., power your car).

Unfortunately… The reality is not so brilliant as one might think. There is one annoying "troublemaker" that adds much gloom to the picture. The name of that troublemaker is **The Second Law of Thermodynamics**

So – even more unpleasant news: we have to go back to physics! If we want to know what the 2nd Law is about, we have to know first what the 1st Law of Thermodynamics says, right?

About the First Law of Thermodynamics:

SYSTEM: A *system:* a single body, or more bodies that in contact with one another.

***U*:** There is a physical quantity called the INTERNAL THERMAL ENERGY of a system – or "internal energy" in short. Conventionally, it is denoted as *U* .

Energy may be added to the system, thus increasing its *U*
(we call such a process "heating").

-- or –

Energy may be taken away from the system, thus lowering its U
(we call such a process "cooling").

Again, the First Law: essentially, it's the <u>Energy Conservation Law</u>, but expressed in a way specifically applying to <u>thermal phenomena</u>:

$$\Delta U = \Delta Q + \Delta W$$

The total change in the system internal energy

The change due to transfer of heat (heat flowing in or out from another system)

The change due to mechanical work done ON the system, or the work delivered BY the system (then -)

IMPORTANT! A common misconception is to confuse HEAT with the INTERNAL ENERGY. Internal energy is the amount of energy contained by the system. Heat is the energy that flows in or out from/to a warmer/cooler body which is in contact with the system.

This slide is not for going through it in detail in class, but rather for you to read before or after the class. This also applies to the next slide.

The First Law was an easy part. But in order to explain what the Second Law talks about, we have to introduce the notion of ENTROPY.

Entropy is widely regarded as one of the most difficult concepts in university physics curriculum. It's a parameter that characterizes the thermal state of a system. Other state parameters are the internal energy ***U***, volume ***V***, the amount of substance (usually expressed as the number of moles ***N*** – a mole consists of 6.022×10^{23} molecules of a given substance – who can tell why such an "exotic" number?), the temperature ***T***, and pressure ***p***. They are all "intuitively clear", am I right?

In contrast, entropy, conventionally denoted as ***S***, is an *abstract function.* Its mathematical definition is not particularly difficult:

$$\text{Differentially}: \; dS = \frac{dQ}{T} \;; \quad \text{hence}: \; S(T) = \int_{T=0}^{T} \frac{dQ}{T}$$

However, for a student it may not be a straightforward thing to understand its physical meaning, and "what it is good for".

4 U to read on your own before the class

Entropy is an even greater challenge for an instructor, than for a student – I mean, doing a "quality work" when teaching this topic. Dr. Tom has been teaching thermal physics at OSU for more then ten years, and he knows that trying to tell everything relevant about entropy in the course of a single class hour would not be a "quality job". Rather, in the thermal physics classes he teaches he spends several hours, introducing the entropy in a systematic manner, step by step. Entropy is not a good topic for being taught in a "crash-course" fashion.

This course is not a thermal physics course, and entropy is "just a small episode". We can only talk about that briefly. Therefore, this presentation is limited to some basic facts that I am asking you to accept without proof.

Here we define the entropy as it is done in *classical thermodynamics,* which is a macroscopic theory. In *statistical thermodynamics*, which is a microscopic approach, one uses a different definition – in terms of thermal disorder: $S = k_B \times \ln \Omega$ where Ω is "the measure of disorder". Both definitions are equivalent, as can be shown – however, the latter is not particularly useful for analyzing the performance of thermal engines, and therefore we will use the "classical definition"

Entropy – important facts "in a nutshell":

The entropy of a *thermally isolated system* (meaning: no heat can be transferred in or out) may only *increase* or *remain constant in time*, but it *cannot decrease.* In other words:

$$\left(\frac{dS}{dt}\right)_{\substack{\text{isolated}\\ \text{system}}} \geq 0.$$

This is the *Second Law of Thermodynamics* – or, rather one of its many formulations. There are many other formulations that one can find in the literature, but they are all equivalent.

One funny fact: the shortest of all those formulations states:

It is not possible to build a Perpetual Motion Machine of the Second Kind

Q: Who derived the Second Law, and how?

A: It has not been "derived" mathematically. It is an EMPIRICAL LAW, based on zillions of experimental results and observations. What scientist only did, they "digested" all that information and formulated The conclusion in the form of a law of physics.

What is the "Perpetual Motion Machine of the Second Kind"? When the Energy Conservation Law was formulated, it became clear that building a purely mechanical perpetual motion device was not possible. But some "inventors" did not give up! They said: *Well, we accept that work cannot be created out of nothing. But note that that oceans are almost infinite reservoirs of thermal energy. Let's convert this energy to work – such a machine would not violate the Energy Conservation Law!*

ENTROPY....

The definition is not very complicated: if a portion of heat ΔQ is transferred in or out of a body of temperature T – an individual body, or a body being a part of a larger system, otherwise isolated) – the change ΔS in the body's/system's entropy S is:

$$\Delta S = \frac{\Delta Q}{T} \tag{9}$$

So, by adding heat you may increase the entropy of a system, and by remowing heat – e.g., through contact with a colder body – we can lower the systems entropy.

Entropy of a single homogenous body (e.g., of a certain amount of water of mass *m*):

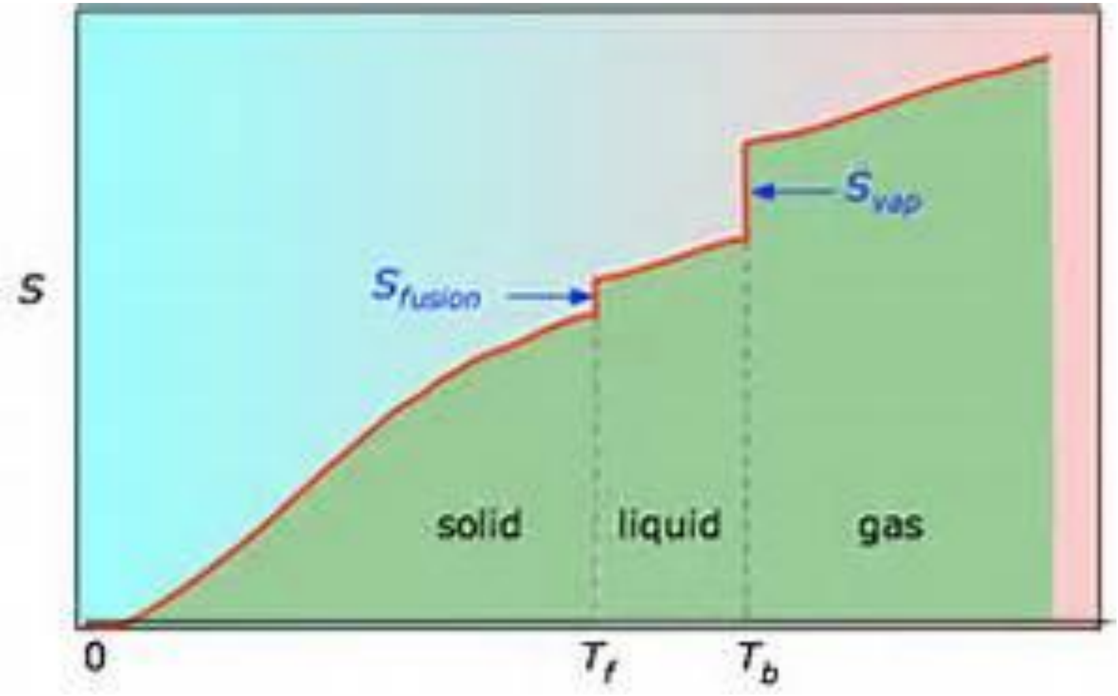


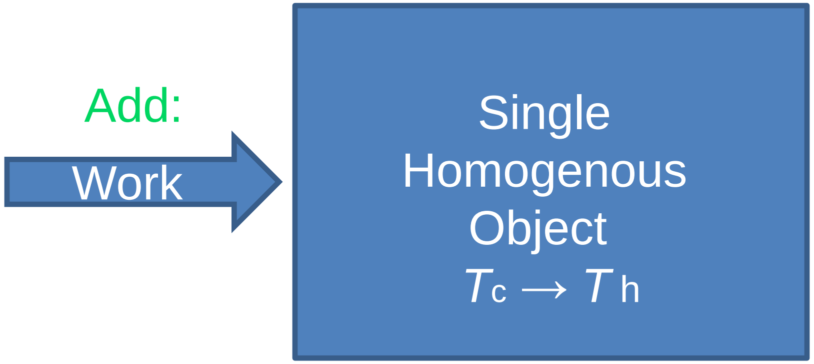
TABLE 7.2 Standard Molar Entropy of Water at Various Temperatures

Phase	Temperature (°C)	$S_m°$ ($J \cdot K^{-1} \cdot mol^{-1}$)
solid	−273 (0 K)	3.4
	0	43.2
liquid	0	65.2
	20	69.6
	50	75.3
	100	86.8
vapor	100	196.9
	200	204.1

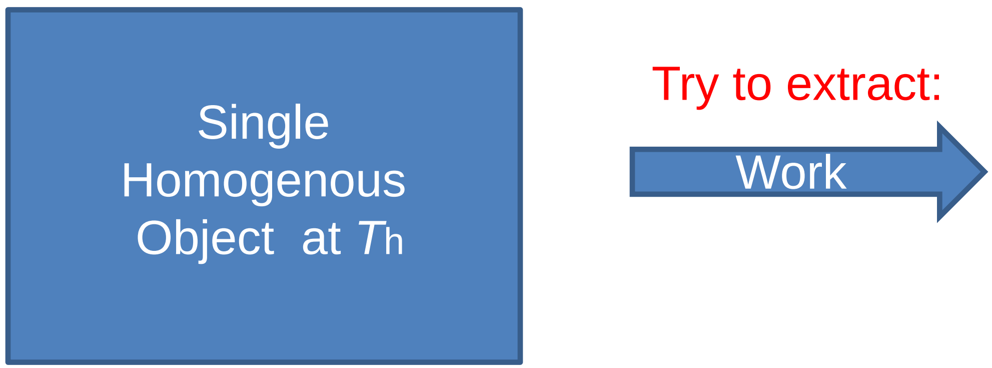
Entropy of such an object is a function of its temperature: $S=S(T)$

But with <u>work</u>, the situation different: the Second Law states that through work one can, yes, ADD entropy to a system, but a process of LOWERING the entropy through "REMOVING" work from the system, CAN NOT HAPPEN!!

It's how Mother Nature ruled .... Like it or not, we cannot do anything to change her verdict.... S cannot be DECREASED!



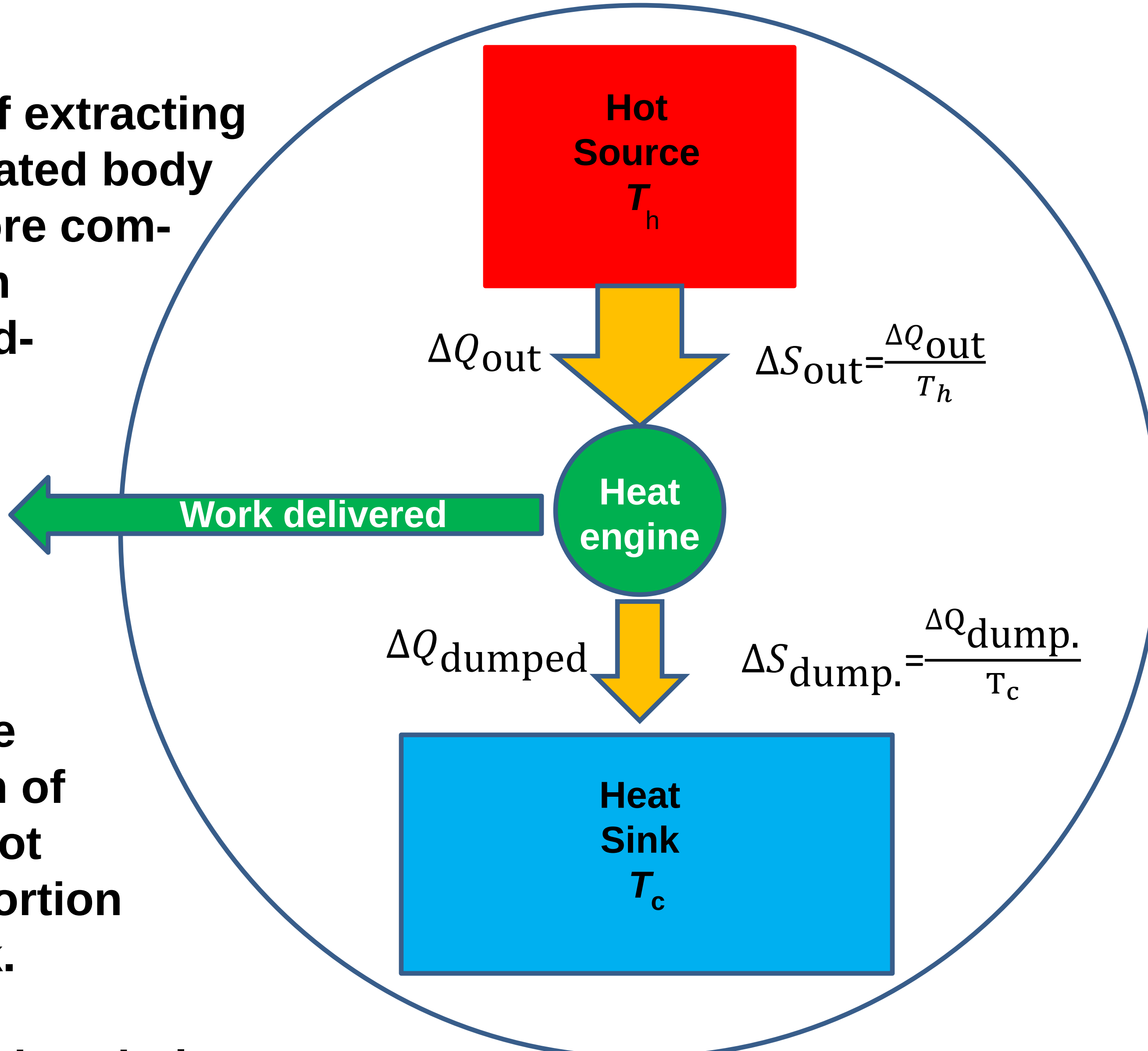
All OK: Internal energy *U* increases,
Temperature increases,
So also the entropy increases.
The Second Law permits!



Impossible!!!

Impossible, because taking away work would lower U, so it would lower the temperature – and consequently, it would <u>lower</u> the entropy – which is forbidden by The Second Law!!!

The only way of extracting work from a heated body is to build a more complicated system containing in addition a "heat engine" and a "heat sink" where heat can be absorded (dumped). The heat engine draws a portion of heat from the hot and dumps a portion to the heat sink.



The entropy of the whole system cannot decrease, so it must be:

$$\Delta S_{dumped} = \Delta S_{out}$$

Continues from the preceding page:
If the entropy of the system considered should not decrease, it must be:

$$\Delta S_{\text{dumped}} = \Delta S_{\text{out}} \tag{1}$$

or

$$\frac{\Delta Q_{\text{dumped}}}{T_{\text{c}}} = \frac{\Delta Q_{\text{out}}}{T_{\text{h}}} \tag{2}$$

This is good news, because $T_{\text{c}} < T_{\text{h}}$**, meaning that** $\Delta Q_{\text{dumped}} < \Delta Q_{\text{out}}$**. From Eq. (2) we obtain:**

$$\Delta Q_{\text{dumped}} = (\Delta Q_{\text{out}}) \cdot \frac{T_{\text{c}}}{T_{\text{h}}} \tag{3}$$

In other words, more heat enters the "heat engine" than is to be dumped from it to the "cold sink". And because of the heat is equivalent to energy, the heat engine can converts the difference to work, and send this work

out of the system, without lowering the system entropy! We get:

$$\Delta W_{\text{delivered}} = \Delta Q_{\text{out}} - \Delta Q_{\text{dumped}} \quad (4)$$

and, combining with Eq. (3), we obtain:

$$\Delta W_{\text{delivered}} = (\Delta Q_{\text{out}}) \cdot \left(1 - \frac{T_{\text{c}}}{T_{\text{h}}}\right) \quad (5)$$

Now the last thing we want to do is to calculate the efficiency of conversion of the thermal energy ΔQ_{out} **taken from the "hot source" to the work delivered,** $\Delta W_{\text{delivered}}$**. We conventionally use the Greek symbol** ϵ **for this efficiency, and define this efficiency and define it as:**

$$\epsilon = \frac{\Delta W_{\text{delivered}}}{\Delta Q_{\text{out}}} \quad (6)$$

So, by combining Eqs. (5) and (6) yield

our final result:

$$\epsilon = \left(1 - \frac{T_{\rm c}}{T_{\rm h}}\right) \tag{7}$$

Or, we often prefer to express the efficiency in percents, then the equation takes form:

$$\epsilon[\%] = \left(1 - \frac{T_{\rm c}}{T_{\rm h}}\right) \cdot 100\% \tag{8}$$

This result describes the <u>highest possible</u> efficiency of a machine converting thermal energy to work.

This result is known as the *Carnot Law*, in honor of Sadi Carnot, a French engineer who derived it in the middle of the XIX Century.

"Sadi" was a good first name for the discoverer of this law, because this law, regretfully, brings us a SAD MESSAGE...

Let's repeat the final conclusion from the preceding page: No heat engine can attain a higher efficiency of converting thermal energy to work than that permitted by the CARNOT LAW.

The consequence are not so pleasant... Let's consider a modern power plant, with using steam turbines. The highest temperature of steam from "state of the arts" flame-heated boilers is $t \approx 550^{\circ}$**C, which translates to** $T = (550 + 273)\mathrm{K} = 823\mathrm{K}$**.**

And an often used "heat sink" is river, lake or sea water, usually of temperature $t \approx 20^{\circ}\mathrm{C}$**, i.e.,** $T = 293\mathrm{K}$**. We get:**

$$\epsilon = 1 - \frac{293\mathrm{K}}{823\mathrm{K}} = 0.644 \qquad (10)$$

It means that only less then 65% of the thermal energy "invested" is converted to work, over 35% "goes down the drain", i.e., is dumped in the heat sink. Not a brilliant performance, you may think, but one can survive with such an efficiency...

But I have more bad news for you: namely, the "Carnot efficiency" is correct only in highly idealized situations. One can build engines which would obey the Carnot Law, yes – look at the following Web sites: e.g., NASA site, the renowned "Hyperphysics" site, or this site in Electropaedia(I like the British "Electropaedia", one can find good "non-nonsense" articles over there).

However, such laboratory-built engines have to work extremely slowly in order to deliver output work consistent with the Carnot Law.

"Extremely slowly' means that they, yes, deliver work – but no POWER. And power is what we really need! We need engines that produce MAXIMUM POWER from a given amount of thermal energy!

To make the long story short: one can make power-maximizing heat engines, there is even a special theory of such engines in thermodynamics, they are called "endoreversible heat engines". The thing is that their operation involves processes which the science of thermodynamics recognizes as "irreversible" – and their nasty effect is that they produce an additional portion of en-

tropy. This extra entropy also has to be removed from the engine, so that even more heat has to be "dumped" into the heat sink. The result is that even less heat can be converted to output work. In short, the efficiency of a power-maximizing heat engine is given by the Chambadal-Novikov formula:

$$\epsilon = 1 - \sqrt{\frac{T_{\mathrm{c}}}{T_{\mathrm{h}}}} \tag{11}$$

Novikov and Chambadal are the two gentlemen who in 1957 independently made pioneering theoretical studies of power-maximizing engines. The theory is quite complicated, I will not even try to discuss its details over here – if you are interested, you may find more in the following Web sources:

Endoreversible thermodynamics, Wikipedia, or in this article – as well as in references listed in these two sources.

The bad news is that, as I say, the above theory is "pretty complicated" – but the good news is that the final theoretical formula is pretty similat to the Carnot Equation – note that there is only an extra square root symbol!

So, it's not the original Carnot's equation, but the Chambadal-Novikov formula we should use for estimating the efficiency of PRACTICAL heat engines. In the

example we considered above, we should use:

$$\epsilon_{\text{practical}} = 1 - \sqrt{\frac{293\text{K}}{823\text{K}}} = 0.403 \tag{12}$$

It means that not 35% energy released from burning fuel, but as much as 60% of this energy "goes down the drain"!

As follows from the example data liste in the Wikipedia site linked above, the Chambadal-Novikow formula yields results that are pretty close to the real thermal efficiencies attained in real power plants. But the 40% efficiency appears to be even too high for most existing thermal power plants, due to extra losses of heat in not-too-well engineered installations – <u>the real efficiency in such plants is seldom higher than 30%</u>.

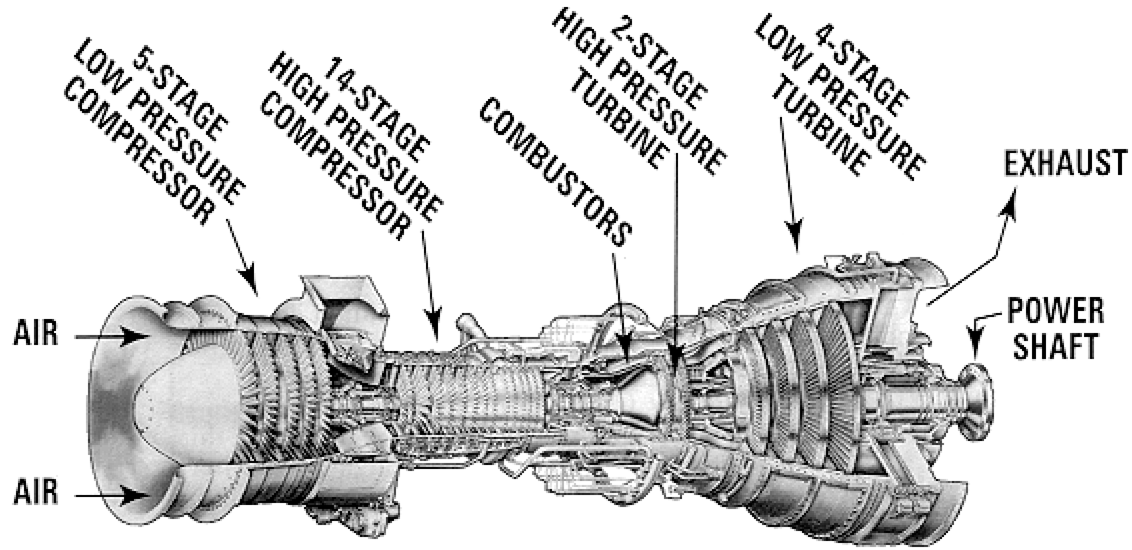
70% of thermal energy released by burning fossil fuels is lost!

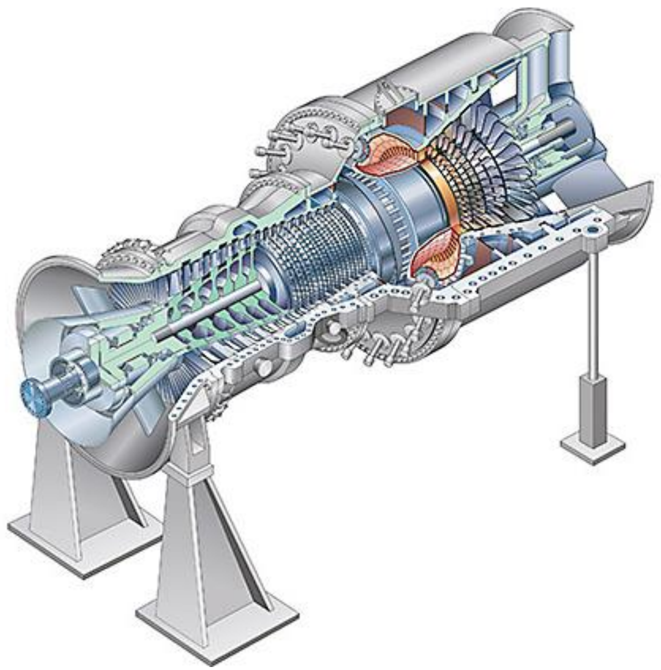
(not engineers should be blamed, but
Mother Nature and her 2nd Law –
but we can stop this wastage
by using energy from
other sources!

A BIT MORE ABOUT TURBINES...

We need to add a few words about *natural gas turbines*. They don't need huge boilers, as steam turbines do. Compressed air an compressed nat,ural gas (nearly pure methane, CH_4, are mixed in a combustion chamber, where the methane and oxygen from the air react (essentially, it's the same process that you certainly know from a gas kitchen stove, and we call it simply "gas burning" – but it's burning at a grand scale!). The volume of the reacted gases increases considerably due to their very high temperature – and a stream of such hot gases is sent to the turbine. Here, things happen in a similar way as in a steam turbine.

Gas turbines are quite compact machines, and certainly good-looking:





As far as the efficiency is concerned, among the whole menagerie of heat engines, modern gas turbines are probably the record-keepers, because their real ϵ value usually exceed 40%, and, reportedly, in some newest model it can be even higher than 60. Such a high efficiency comes from the fact that the temperature of the inlet gases coming from the combustion chamber may be as high as 1600 °C, or nearly 1900 K – whereas, as we remember, in the best steam turbines the inlet steam temperature is 800-850 K. If we insert $T_{\mathrm{h}} = 1900$ K, and $T_{\mathrm{c}} = 300$ K into Eq. (12), we indeed get an ϵ value close to 60%.

FUELS

The ***heat of combustion*** **– in other words, the amount of thermal energy released in the process of burning a mass unit of a given fuel – is a very Important characteristic.**

A.k.a. *natural gas* – it is the "greenest" fuel of all fossil fuels. → Methane

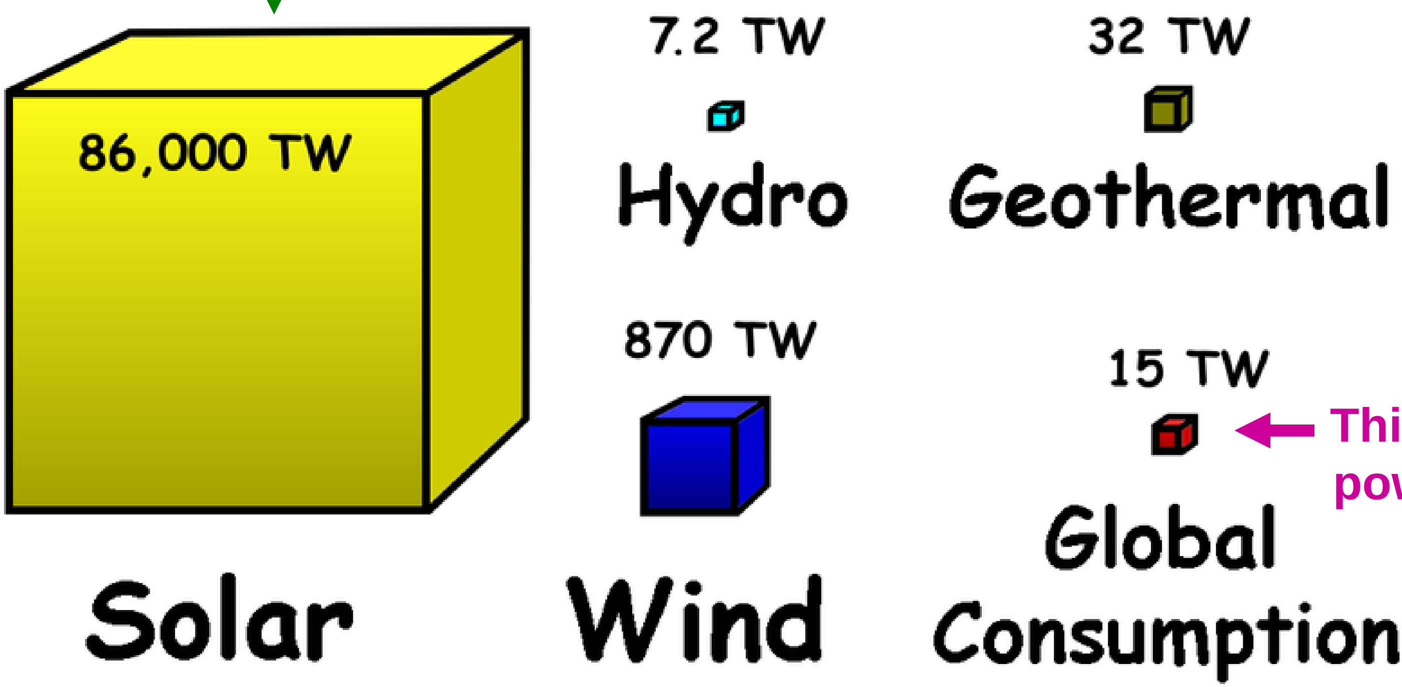
Fuel	MJ/kg	BTU/lb
Hydrogen	141.80	61,000
Methane	55.50	23,900
Ethane	51.90	22,400
Propane	50.35	21,700
Butane	49.50	20,900
Pentane		
Gasoline	47.30	20,400
Paraffin	46.00	19,900
Kerosene	46.20	
Diesel	44.80	19,300
Coal (Anthracite)	27.00	14,000
Coal (Lignite)	15.00	8,000
Wood	15.00	6,500
Peat (damp)	6.00	2,500
Peat (dry)	15.00	6,500

In the table, there are the combustion heat data for major fuels we use today, and for hydrogen, which will hopefully be the main fuel in the.

Missing are the data for ethyl alcohol and methyl alcohol (methanol). Their heat of combustion is about 70% of that for gasoline.

Let's talk about the pollutions resulting from fuel burning. One is the "waste heat" – about ¾ of all thermal energy released by burning all kinds of fuels is "dumped" to "heat sinks". The remaining ¼ also ends up as heat. Is it a serious problem? Well, not yet:

Total power received by Earth in the form of sunlight:



This is the total power released to the environment by us. Much? Not really…

Chemical pollutions:

The cleanest of all fuels is hydrogen:

$$2H_2 + O_2 \rightarrow 2H_2O$$ **-- just water vapor!**

Water vapor is a greenhouse gas, but it comes from oceans, lakes, rivers, from the soil and plants. Water vapor from fuel burning is not a significant figure in comparison to those natural sources. Unfortunately, hydrogen is not yet used at a major scale. Why? We will talk about that soon!

Methane, or "natural gas", is the second greenest of all fuels, and the greenest of all fossil fuels.

$$CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$$

$$CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$$

How much carbon dioxide is released when burning one kilogram of methane?

Let's calculate:
The atomic weight of H is 1;
The atomic weight of C is 12;
The atomic weight of O is 16;

Hence:
The molecular weight of CH4 is 12+4 = 16;
The molecular weight of H2O is 2+16 = 18;
The molecular weight of CO2 is 12+32 = 44;

CO_2 :

$$\frac{16}{1\,\text{kg}} = \frac{44}{x}$$

$$x = \frac{44}{16} \times 1\,\text{kg} = 2.75\,\text{kg}$$

H_2O :

$$\frac{16}{1\,\text{kg}} = \frac{2 \times 18}{y}$$

$$y = \frac{36}{16} \times 1\,\text{kg} = 2.25\,\text{kg}$$

$$O_2 : \quad \frac{16}{1\,\text{kg}} = \frac{2 \times 32}{z} \quad \Rightarrow z = \frac{64}{16} \times 1\,\text{kg} = 4.0\,\text{kg}$$

Coal: with a sufficiently good approximation for our calculations, it is an almost pure carbon.

$$C + O_2 \rightarrow CO_2$$

$$\frac{12}{1\,\mathrm{kg}} = \frac{44}{x}$$

$$x = \frac{44}{12} \times 1\,\mathrm{kg} = 3.67\,\mathrm{kg}$$

Compare with natural gas: burning 1 kg of coal produces 3.67/2.75 times more carbon dioxide than burning 1 kg of methane – 33% more.

Take combustion heat data: methane – 55.5 MJ/kg; coal – 27 MJ/kg

So, obtaining the same amount of heat from coal as from methane releases (55.5/27)x1.33 = 2.7 times more carbon dioxide to the air!

QUIZ 1

The heat of combustion of ethanol, C_2H_6O is 29.7 MJ/kg. Find: (a) how much CO_2 is emitted by burning 1 kilogram of ethanol, and (b) how much CO_2 is emitted per each MJ of thermal energy released by ethanol burning. The latter result, as you will find, is a small number (0.0...). So, Additionally, express the latter result in more convenient units, kg/GJ, and kg/kWh.

QUIZ 2

The manufactures of electric cars need to know quite well how much energy their cars use per one mile. The figure for a compact car, such as, e.g., Nissan Leaf, is about 0.25 kWh/mile.

Suppose that you are an owner of a car of similar size as Nissan Leaf, with a gasoline engine. Suppose for a moment that the efficiency of this engine is 100%. So, how far would you be able to get on 1 US Gallon of gasoline? One Gallon is 3.785 liters, and the density of normal commercial gasoline can be taken as 0.75 kg/liter.

If correctly done, your calculations should yield a result larger than 100 miles. Now, think of how far a REAL gasoline car can travel on 1 Gallon of fuel – and estimate, what is the practical efficiency of an automobile gasoline engine? (the result may be a bit shocking – which is precisely why I'm giving you this quiz).