Energy and Power

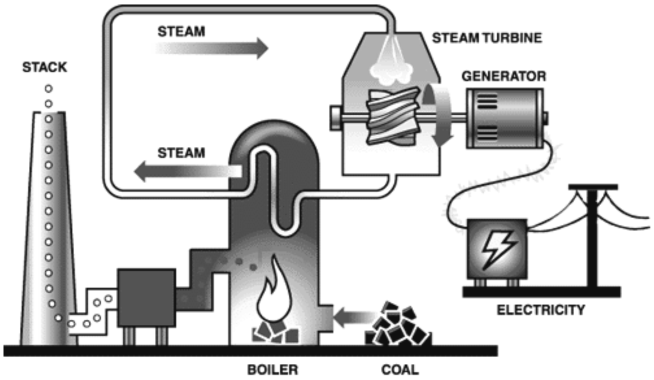
IB 12

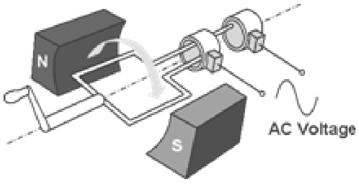
Power Generation in a typical electrical power plant

a) Some fuel is used (coal, natural gas, oil, uranium) to release thermal energy which is used to boil water to make steam.

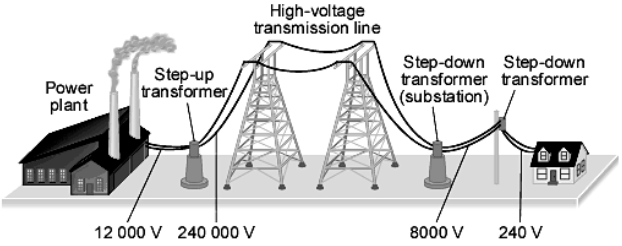
b) **Generator (Dynamo)** - Steam turns turbines attached to coils of wire which turn in a magnetic field inducing an alternating potential difference.

c) Potential difference is stepped up by transformers in order to reduce I^2R loss of power in transmission lines then stepped down for consumer use.

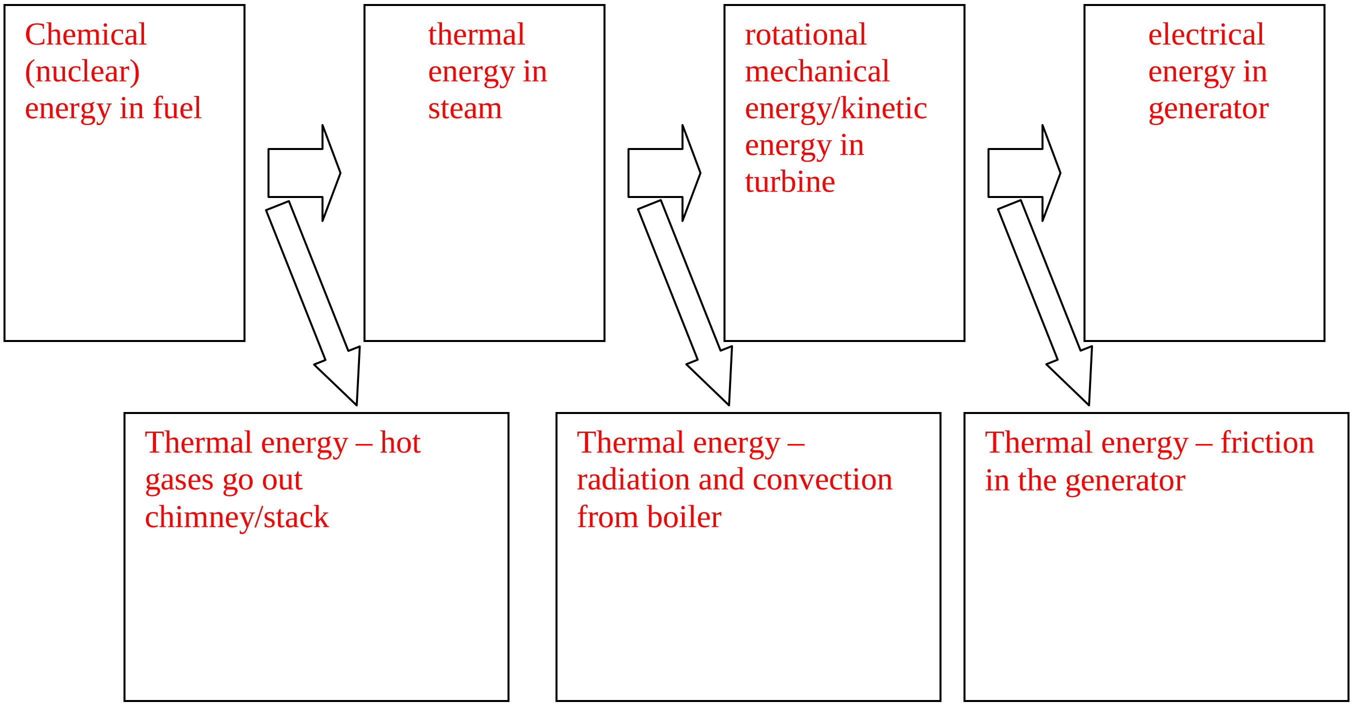




Alternating Current Generator



What are the energy transformations that take place?



Chemical (nuclear) energy in fuel

thermal energy in steam

rotational mechanical energy/kinetic energy in turbine

electrical energy in generator

Thermal energy – hot gases go out chimney/stack

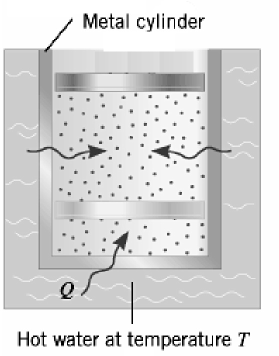
Thermal energy – radiation and convection from boiler

Thermal energy – friction in the generator

Degraded energy: energy transferred to the surroundings that is no longer available to do useful work – can't be converted into other forms

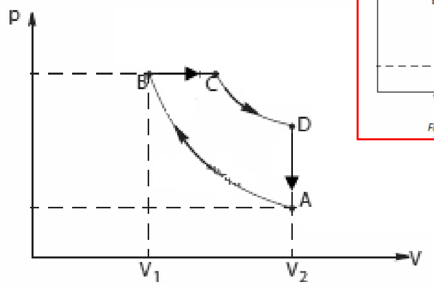
Why does the generation of electrical power involve the degradation of energy?

1. Thermal energy can be completely converted to work in a single process.



Example:
isothermal expansion
$Q = \Delta U + W$
$\Delta U = 0$
so $Q = W$

2. A continuous conversion of thermal energy into work requires a cyclical process.



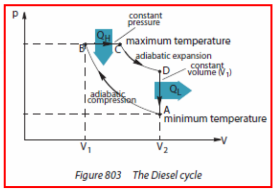


Figure 803 The Diesel cycle

Second Law of Thermodynamics:

1) The total entropy of the universe is increasing.

2) No cyclical process (engine) is ever 100% efficient. Some energy is transferred out of the system (lost to the surroundings) as unusable energy (degraded energy).

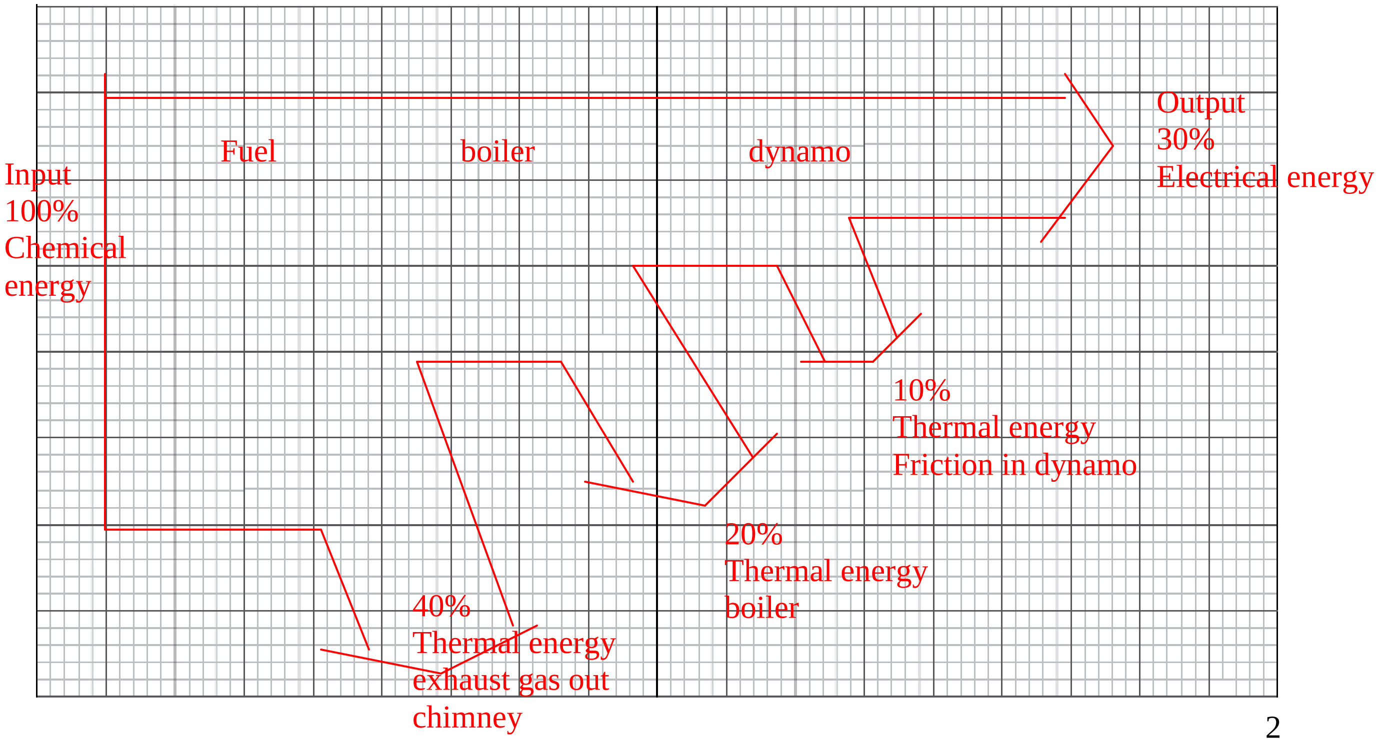
Sankey diagrams (energy flow diagrams): used to keep track of energy transfers and transformations

1) Thickness of arrow is proportional to amount of energy.

2) Degraded energy points away from main flow of energy.

3) Total energy in = total energy out.

Fuel	Typical Efficiency
Coal	30-35%
Natural Gas	50%
Oil	30-35%



Fuels

Fuel: source of energy (in a useful form)

How does a fuel work? A fuel releases energy by changing its chemical (or nuclear) structure. Chemical (or nuclear) bonds are broken reducing the fuel's internal potential energy but increasing the kinetic energy of the substance's particles which is seen macroscopically as an increase in the temperature of the substance. It is this thermal energy that is used to heat the water that will change to steam to turn the generator's turbines.

Fossil fuels: coal, oil, natural gas, peat

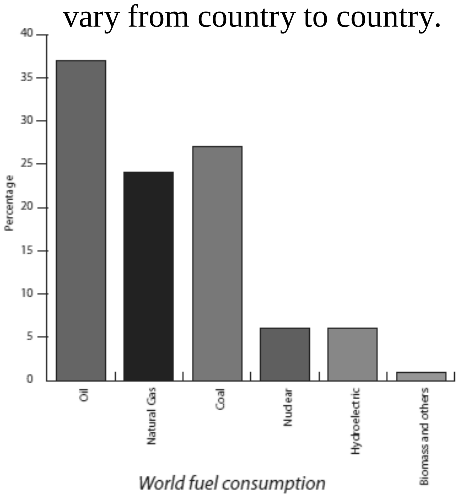
Origins of fossil fuels: organic matter decomposed under conditions of high temperature and pressure over millions of years

Non-renewable fuels: rate of production of fuel is much smaller than rate of usage so fuel will be run out - limited supply

Renewable fuels: resource that cannot be used up or is replaced at same rate as being used

Type of fuel	**Renewable?**	**CO_2 emissions?**
Fossil fuels	No	Yes
Nuclear	No	No
Hydroelectric	Yes	No
Wind	Yes	No
Solar	Yes	No
Wave	Yes	No

This histogram shows the relative proportions of world use of the different types of energy sources, though it will vary from country to country.



World fuel consumption

NOTE: In most instances, the prime energy source for world energy is . . . the Sun.

Exceptions: nuclear, tidal (Moon)

Fossil Fuel Power Production

Historical and geographical reasons for the widespread use of fossil fuels:

1. industrialization led to a higher rate of energy usage (Industrial Revolution)
2. industries developed near large deposits of fossil fuels (coal towns)

Transportation and storage considerations:

1. Natural gas is usually transported and stored in pipelines.

   Advantages: cost effective

   Disadvantages: unsightly, susceptible to leaks, explosions, terrorist activities, political instability (withholding use of pipelines or terminals for political reasons)

2. Many oil refineries are located near the sea close to large cities. Oil is transported via ships, trucks, and pipelines.

   Advantages: workforce and infrastructure in place, easy access to shipping

   Disadvantages: oil spills and leakage, hurricanes, terrorist activities

3. Power stations using coal and steel mills are usually located near coal mines.

   Advantages: minimizes shipping costs

   Disadvantages: environmental impact (strip mining), mine cave-ins

Use of fossil fuels for generating electricity

Advantages:	Disadvantages:
1. high energy density	1. combustion produces pollution, especially SO_2 (acid rain)
2. relatively easy to transport	2. combustion produces greenhouse gases (CO_2)
3. cheap compared to other sources	3. extraction (mining, drilling) damages environment
4. power stations can be built anywhere	4. nonrenewable
5. can be used in the home	5. coal-fired plants need large amounts of fuel

Energy density of a fuel: the ratio of the energy released from the fuel to the mass of the fuel consumed

Formula: $D_e = E/m$ Units: J/kg

Use: to compare different types of fuels

How is choice of fuel influenced by energy density?

Fuels with higher energy density cost less to transport and store

Fuel	**Energy Density (MJ/kg)**
Fusion fuel	300,000,000
Uranium-235	90,000,000
Natural gas	53.6
Gasoline (Petrol)	46.9
Diesel	45.8
Biodiesel	42.2
Crude oil	41.9
Coal	32.5
Sugar	17.0
Wood	17.0
Cow dung	15.5
Household waste	10

1. An oil-fired power station produces 1000 MW of power.

   a) How much energy will the power station produce in one day?

$$P = \frac{E}{t}$$

$$E = Pt$$

$$E = (1000 \text{ x } 10^6 W)(24x3600)$$

$$E = 8.6x10^{13} J$$

   b) Estimate how much oil the power station needs each day.

$$eff = \frac{\text{useful out}}{\text{total in}} = \frac{E_{out}}{E_{in}}$$

$$.35 = \frac{8.6x10^{13} J}{E_{in}}$$

$$E_{in} = 2.46x10^{14} J$$

$$D_e = \frac{E}{m}$$

$$41.9x10^6 \frac{J}{kg} = \frac{2.46x10^{14} J}{m}$$

$$m = 5.9x10^6 kg$$

2. A 250 MW coal-fired power plant burns coal with an energy density of 35 MJ/kg. Water enters the cooling tower at a temperature of 350 K and leaves at a temperature of 293 K and the water flows through the cooling tower at a rate of 4200 kg/s.

a) Calculate the thermal energy removed from the water in the cooling towers each second.

$$Q = mc\Delta T$$
$$Q = (4200kg)(4.19x10^3 \frac{J}{kgK})(350-293)$$
$$Q = 1.0x10^9 J$$

$$P = \frac{E}{t}$$
$$P = \frac{1.0x10^9 J}{1s}$$
$$P = 1.0x10^9 W = 1000MW$$

b) Assuming the only significant loss of energy is this thermal energy of the water, calculate the energy produced by the combustion of coal each second.

$$E_{in} = E_{out}$$
$$E_{in} = 1000 \text{ MJ} + 250 \text{ MJ}$$
$$\text{E}_{in} = 1250MJ$$

c) Calculate the mass of coal burned each second.

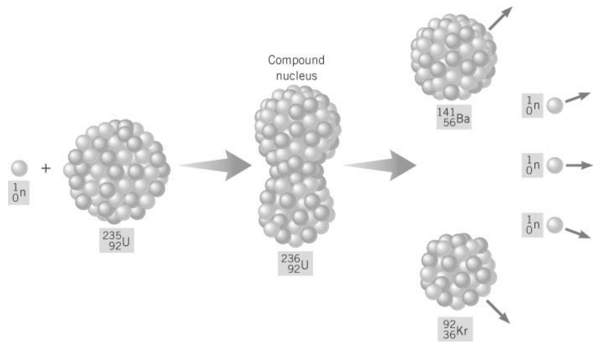
$$eff = \frac{\text{useful out}}{\text{total in}} = \frac{P_{out}}{P_{in}}$$
$$eff = \frac{250MW}{1250MW}$$
$$eff = .20$$

$$D_e = \frac{E}{m}$$
$$35x10^6 \frac{J}{kg} = \frac{1250x10^6 J}{m}$$
$$m = 36kg$$

Nuclear Energy

Most common source: fissioning of uranium-235 with conversion of some mass into energy

Process:



a) unstable uranium nucleus is bombarded with a neutron and splits into two smaller nuclei and some neutrons

   Why use neutrons? Neutral, not repelled by nucleus

b) rest mass of products is less than reactants so some matter is converted into energy

   Form of energy: KE of products (thermal energy)

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$$

c) released neutrons strike other uranium nuclei causing further fissions

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1) A particular nuclear reactor uses uranium-235 as its fuel source. When a nucleus of uranium-235 absorbs a neutron, the following reaction can take place:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{144}_{54}Xe + ^{90}_{38}Sr + x^{1}_{0}n$$

a) How many neutrons are produced in the reaction? 2

b) Use the information to show that the energy released in the reaction is approximately 180 MeV.

rest mas of $^{235}_{92}U = 2.1895 \text{ x } 10^{5}$ MeV c^{-2}

rest mas of $^{1}_{0}n = 939.56$ MeV c^{-2}

rest mas of $^{144}_{54}Xe = 1.3408 \text{ x } 10^{5}$ MeV c^{-2}

rest mas of $^{90}_{38}Sr = 8.3749 \text{ x } 10^{5}$ MeV c^{-2}

2. The energy released by one atom of carbon-12 during combustion is approximately 4 eV. The energy released by one atom of uranium-235 during fission is approximately 180 MeV.

   a) Based on this information, determine the ratio of the energy density of uranium-235 to that of carbon-12. (Then, check your answer with the given table of energy densities.)

$$mass = \frac{N}{N_A} \text{ x molar mass}$$

$$\text{mass} = \frac{1}{6.02x10^{23}} \text{ x .235 kg}$$

$$\text{mass}=3.90\text{x}10^{-25} kg$$

$$mass = \frac{N}{N_A} \text{ x molar mass}$$

$$\text{mass} = \frac{1}{6.02x10^{23}} \text{ x .012 kg}$$

$$\text{mass}=1.99\text{x}10^{-26} kg$$

$$\left(\frac{180x10^6 eV}{1}\right)\left(\frac{1.60x10^{-19} J}{1eV}\right) = 2.88x10^{-11} J$$

$$\left(\frac{4eV}{1}\right)\left(\frac{1.60x10^{-19} J}{1eV}\right) = 6.40x10^{-19} J$$

$$D_e = \frac{2.88x10^{-11} J}{3.90x10^{-25} kg} = 7.38x10^{13} J/kg$$

$$= 7.38x10^7 MJ/kg$$

$$D_e = \frac{6.40x10^{-19} J}{1.99x10^{-26} kg} = 3.22x10^7 J/kg$$

$$= 32.2 MJ/kg$$

$$\frac{D_e \text{ U-235}}{D_e \text{ C-12}} = \frac{7.38x10^7}{32.2} = 2.3x10^6$$

   b) Based on your answer above, suggest one advantage of uranium-235 compared with fossil fuels.

Higher energy density implies that uranium will produce more energy per kilogram – less fuel needed to produce the same amount of energy

Nuclear Fuel and Reactors

IB 12

Naturally Occurring Isotopes of Uranium:

1) **Uranium-238:** most abundant (99.3%) but not used for fuel since it has a very small probability of fissioning when it captures a neutron.

2) **Uranium-235:** rare (0.3%) but used for fuel since it has a much greater probability of fissioning when captures a neutron but must be a low-energy neutron (thermal neutron).

Thermal Neutron: low-energy neutron (≈1eV) that favors fission reactions – energy comparable to gas particles at normal temperatures

Fuel Enrichment: process of increasing proportion of uranium-235 in a sample of uranium

1) formation of gaseous uranium (uranium hexafluoride) from uranium ores

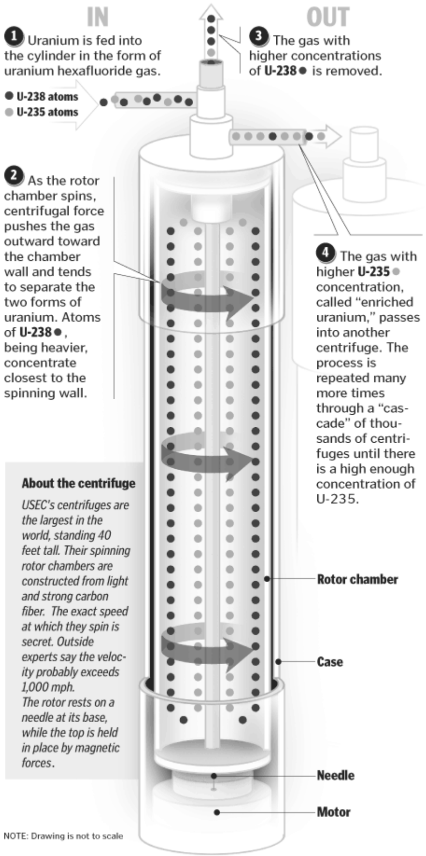
2) separated in gas centrifuges by spinning – heavier U-238 moves to outside

3) increases proportion of U-235 to about 3-5% of total (low enrichment)

4) This low enriched hex is compressed and turned into solid uranium-oxide fuel pellets which are packed into tubes called **fuel rods** which will be used in the core of a nuclear reactor.

Advantage: More uranium is available for fission and a chain reaction can be sustained in a reactor to produce nuclear energy.

Disadvantage: If the fuel is enriched to a high level (90% = weapons grade) it can be used in the core of a nuclear weapon. Possession of nuclear weapons is seen by many to be a threat to world peace.



❶ Uranium is fed into the cylinder in the form of uranium hexafluoride gas.

❷ As the rotor chamber spins, centrifugal force pushes the gas outward toward the chamber wall and tends to separate the two forms of uranium. Atoms of **U-238** ●, being heavier, concentrate closest to the spinning wall.

❸ The gas with higher concentrations of **U-238** ● is removed.

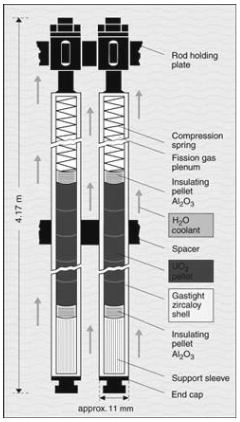
❹ The gas with higher **U-235** ● concentration, called "enriched uranium," passes into another centrifuge. The process is repeated many more times through a "cascade" of thousands of centrifuges until there is a high enough concentration of U-235.

About the centrifuge

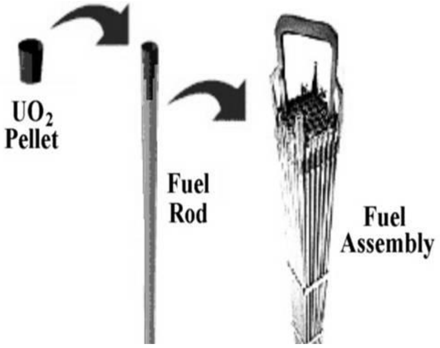
USEC's centrifuges are the largest in the world, standing 40 feet tall. Their spinning rotor chambers are constructed from light and strong carbon fiber. The exact speed at which they spin is secret. Outside experts say the velocity probably exceeds 1,000 mph.
The rotor rests on a needle at its base, while the top is held in place by magnetic forces.

NOTE: Drawing is not to scale

A cascade of centrifuges used for enriching uranium



Nuclear Fuel Rods



Chain Reaction – neutrons released from one fission reaction go on to initiate further reactions

Uncontrolled nuclear fission: nuclear weapons

Controlled nuclear fission: nuclear power production

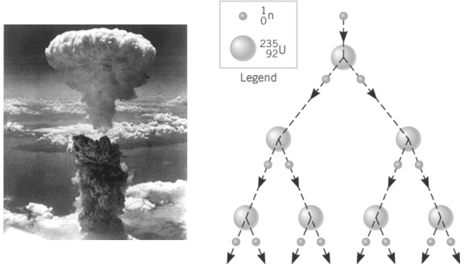
1) Some material (control rod) absorbs excess neutrons before they strike another nucleus.

2) This leaves only one neutron from each reaction to produce another reaction.

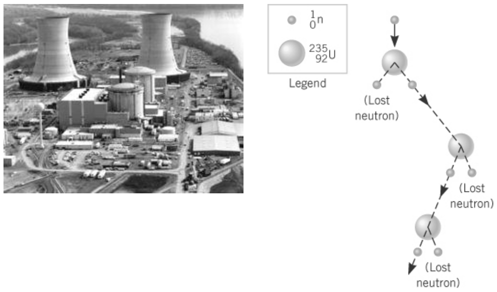
3) If the total mass of uranium used is too small, too many neutrons will escape without causing further fissions so the reaction cannot be sustained.

Critical Mass: minimum mass of radioactive fuel (uranium) needed for a chain reaction to occur

Uncontrolled Chain Reaction



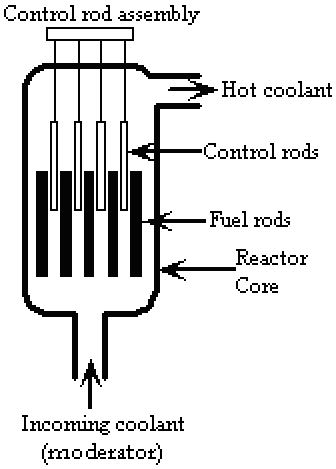
Controlled Chain Reaction



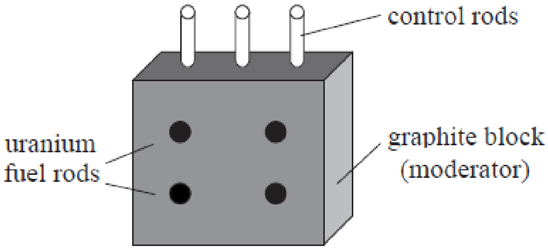
The Nuclear Reactor Core

Fuel Rods: enriched solid uranium

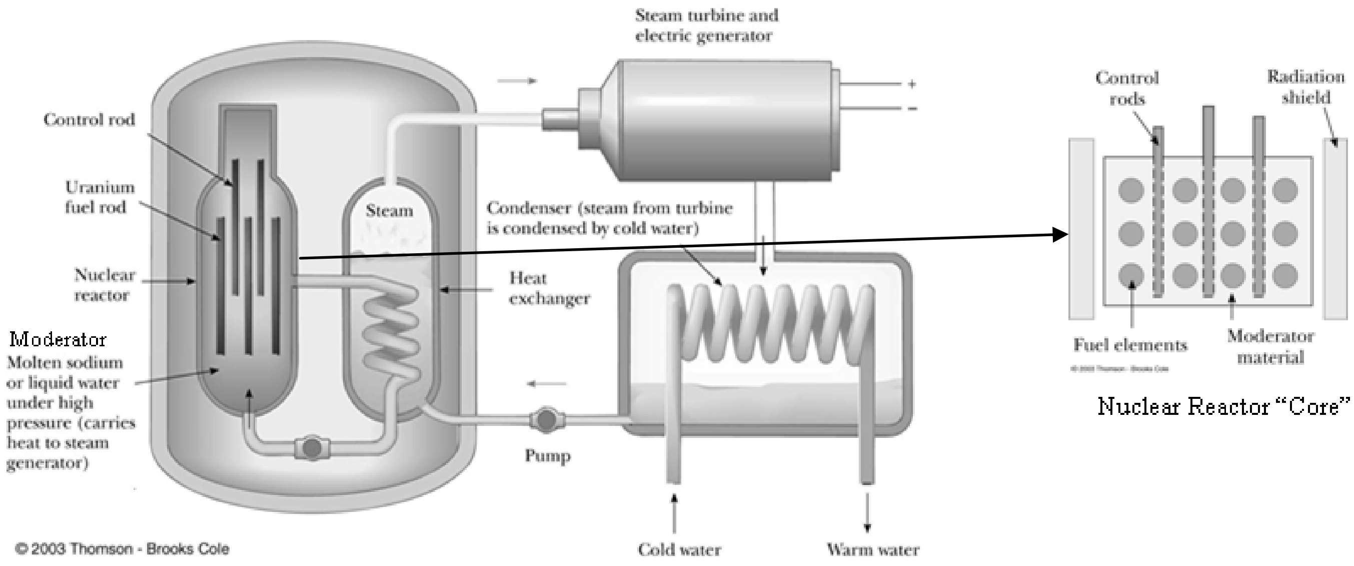
When neutrons are emitted from a fission reaction in the fuel rods, they have a very high kinetic energy and will pass right out of the fuel rod without colliding with another uranium nucleus to cause more fission. High energy neutrons cannot sustain a chain reaction. Therefore, a material is needed to slow them down. Typically, a material like water or graphite (called a "**moderator**") is used to slow down these high-energy neutrons down to "thermal levels" (thermal neutrons ≈ 1 eV) for use in further fission reactions to sustain the chain reaction. The high-energy neutrons slow down when they collide with the atoms in the moderator.



To control the rate at which the thermal energy is produced, and therefore to control the temperature of the reactor core, **control rods** are used to speed up or slow down the chain reaction. These are rods made of a neutron-absorbing substance, like cadmium or boron. They are inserted in between the fuel rods and raised or lowered as needed. If the reaction is proceeding too fast (too hot) the rods are lowered and enough thermal neutrons are absorbed to slow down the reaction to the desired level. Conversely, if the reaction is too slow, the control rods are raised allowing more thermal neutrons to collide with uranium nuclei.



Main components of a pressurized-water reactor (PWR)



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How is the thermal energy released in the fission reactions used to generate electricity?

The **coolant** (which is often the same as the moderator) is fluid circulating around the fuel rods in the reactor core and is heated up by the thermal energy released in the fission chain reaction.
This coolant in a closed loop (primary loop) flows through pipes in a tank of water known as the "**heat exchanger.**" Here the thermal energy of the hot coolant is transferred to cooler water in a secondary loop which turns it to steam. This steam expands against fan blades of turbines and turns a magnet is a coil of wire to generate electricity.

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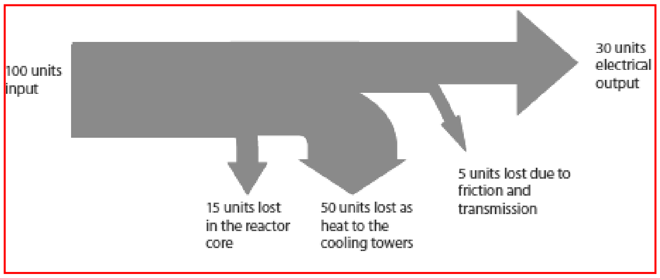
1. State the energy transformations in using nuclear fuels to generate electrical energy:

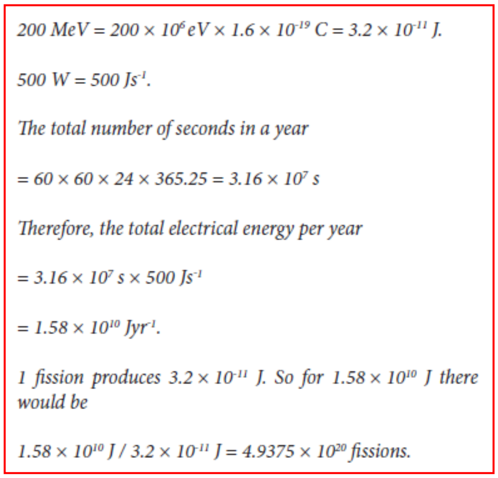
Nuclear energy in fuel….thermal energy in coolant . . thermal energy in steam in heat exchanger…rotational mechanical energy/kinetic energy…electrical energy in turbines

2. Sketch a Sankey diagram for a typical nuclear power plant.



3. Suppose the average power consumption for a household is 500 W per day. Estimate the amount of uranium-235 that would have to undergo fission to supply the household with electrical energy for a year. State some assumptions made in your calculation.

Assume plant is 100% efficient
Assume 200 MeV per fission



200 MeV $= 200 \times 10^{6}\,eV \times 1.6 \times 10^{-19}\,C = 3.2 \times 10^{-11}\,J.$

500 W $= 500\,Js^{-1}.$

The total number of seconds in a year

$= 60 \times 60 \times 24 \times 365.25 = 3.16 \times 10^{7}\,s$

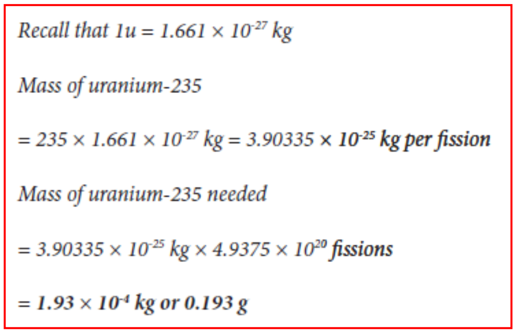
Therefore, the total electrical energy per year

$= 3.16 \times 10^{7}\,s \times 500\,Js^{-1}$

$= 1.58 \times 10^{10}\,Jyr^{-1}.$

1 fission produces 3.2×10^{-11} *J. So for* 1.58×10^{10} *J there would be*

$1.58 \times 10^{10}\,J / 3.2 \times 10^{-11}\,J = 4.9375 \times 10^{20}$ *fissions.*



Recall that $1u = 1.661 \times 10^{-27}\,kg$

Mass of uranium-235

$= 235 \times 1.661 \times 10^{-27}\,kg = 3.90335 \times 10^{-25}$ **kg per fission**

Mass of uranium-235 needed

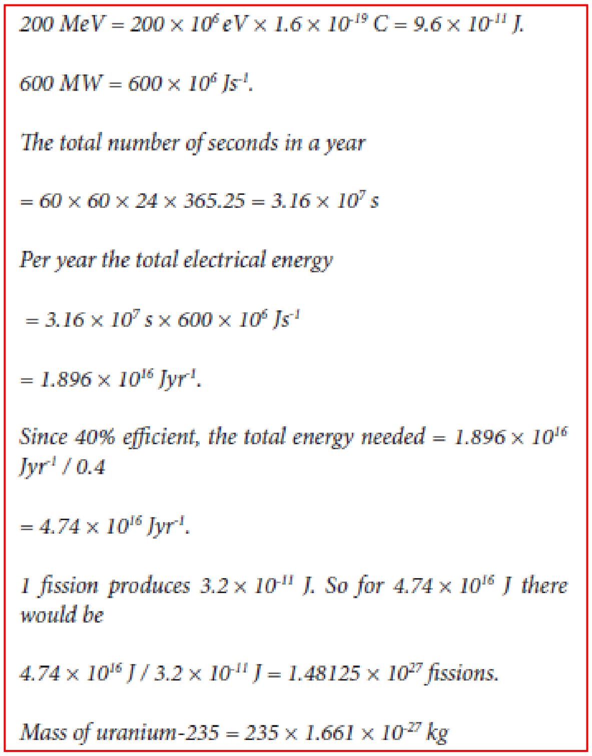
$= 3.90335 \times 10^{-25}\,kg \times 4.9375 \times 10^{20}$ **fissions**

$= \mathbf{1.93 \times 10^{-4}}$ **kg or 0.193 g**

4. A fission reaction taking place in a nuclear power station might be:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$$

Estimate the initial amount of uranium-235 needed to operate a 600 MW reactor for one year assuming 40% efficiency and 200 MeV released for each fission reaction.



200 MeV = 200×10^6 eV × 1.6×10^{-19} C = 9.6×10^{-11} J.

600 MW = 600×10^6 Js^{-1}.

The total number of seconds in a year

= $60 \times 60 \times 24 \times 365.25 = 3.16 \times 10^7$ s

Per year the total electrical energy

= 3.16×10^7 s × 600×10^6 Js^{-1}

= 1.896×10^{16} Jyr^{-1}.

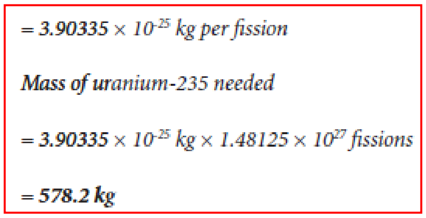
Since 40% efficient, the total energy needed = 1.896×10^{16} Jyr^{-1} / 0.4

= 4.74×10^{16} Jyr^{-1}.

1 fission produces 3.2×10^{-11} J. So for 4.74×10^{16} J there would be

4.74×10^{16} J / 3.2×10^{-11} J = 1.48125×10^{27} fissions.

Mass of uranium-235 = $235 \times 1.661 \times 10^{-27}$ kg



= 3.90335×10^{-25} kg per fission

Mass of uranium-235 needed

= 3.90335×10^{-25} kg × 1.48125×10^{27} fissions

= 578.2 kg

Plutonium and Nuclear Reactors

Plutonium-239 is another nuclide used as nuclear fuel because of the energy it releases when it undergoes fission. However, it is not as naturally abundant as uranium and so it typically must be artificially produced as a by-product of uranium fission. In a uranium-fueled reactor, as the U-235 depletes over time, the amount of Pu-239 increases. This plutonium is then extracted (by reprocessing of the uranium fuel rods) for use in a plutonium reactor or in a nuclear warhead.

How is plutonium-239 produced in a uranium reactor? It actually is produced from the non-fissionable isotope uranium-238 that occurs in large amounts in fuel rods. Uranium-238 doesn't undergo nuclear fission but is considered "fertile" since it produces plutonium-239 by the following process.

$$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{92}U \rightarrow ^{239}_{93}Np + ^{0}_{-1}e + \overline{\nu}$$

$$^{239}_{93}Np \rightarrow ^{239}_{94}Pu + ^{0}_{-1}e + \overline{\nu}$$

$$^{239}_{94}Pu + ^{1}_{0}n \rightarrow ^{140}_{56}Ba + ^{96}_{38}Sr + 4^{1}_{0}n$$

rest mass of $^{239}_{94}Pu = 239.052157u$

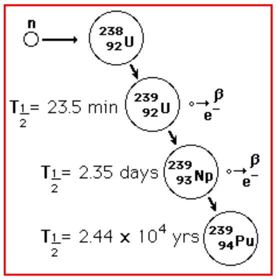
rest mass of $^{1}_{0}n = 1.008665u$

rest mass of $^{140}_{56}Ba = 139.910581u$

rest mass of $^{96}_{38}Sr = 95.921750u$

1. Complete the nuclear reactions listed above.

2. Construct a nuclear energy level diagram for the series of nuclear reactions listed above.

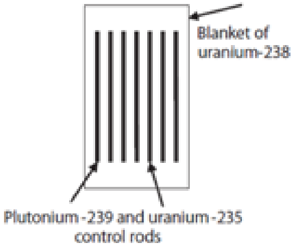


3. Determine the amount of energy released in the fissioning of plutonium-239.

m = m + Δm

0.19383 u = 180 MeV

Some uranium reactors are even specially designed to produce (or "breed") large amounts of plutonium and are known as **breeder reactors**. They are designed so that the fuel rods are surrounded by a blanket of U-238 so that neutrons escaping from the U-235 fissions will induce the conversion of this U-238 to Pu-239.

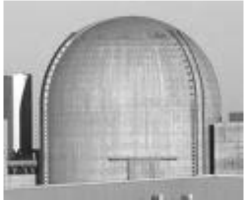


Core of a Breeder Reactor

Safety Issues and Risks in the Production of Nuclear Power

Uranium Mining:

- **open-cast mining:** environmental damage, radioactive waste rock (tailings)
- **underground mining:** release of radon gas (mines need ventilation), radioactive rock is dangerous for workers, radioactive waste rock (tailings)
- **leaching:** Solvents are pumped underground to dissolve the uranium and then pumped back out. This leads to contamination of groundwater.



Thermal Meltdown:
Overheating and melting of fuel rods may be caused by a malfunction in the cooling system or the pressure vessel. This overheating may cause the pressure vessel to burst sending radioactive material and steam into atmosphere (as in Chernobyl, Ukraine 1986). Hot material may melt through floor (as in Three Mile Island, Pennsylvania 1979), a scenario dubbed the “China syndrome.” The damage from these possible accidents is often limited by a containment vessel and a containment building.

Nuclear Waste:

- **Low-level waste:** Radioactive material from mining, enrichment and operation of a plant must be disposed of. It’s often left encased in concrete.

- **High-level waste:** a major problem is the disposal of spent fuel rods. Some isotopes have ½ lives of thousands of years. Plutonium’s is 240,000 years.

    1) Some are stored under water at the reactor site for several years to cool off then sealed in steel cylinders and buried underground.

    2) Some are reprocessed to remove any plutonium and useful uranium. The remaining isotopes have shorter ½ lives and the long-term storage need is reduced.

Nuclear Weapons Manufacture:

- Enrichment technology could be used to make weapons grade uranium (85%) rather than fuel grade (3%)

- Plutonium is most used isotope in nuclear weapons and can be gotten from reprocessing spent fuel rods

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Comparing Nuclear Fuel to Fossil Fuel

Advantages:	Disadvantages:
1. No global warming effect – no CO_2 emissions	1. Storage of radioactive wastes
2. Waste quantity is small compared with fossils fuels	2. Increased cost over fossil fuel plants
3. Higher energy density	3. Greater risks in an accident (due to radioactive contamination)
4. Larger reserves of uranium than oil	

Nuclear Fusion

Nuclear Fusion: Two light nuclei combine to form a more massive nucleus with the release of energy.

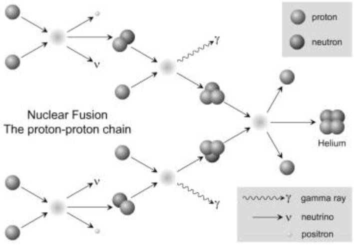
Naturally occurring fusion: main source of Sun’s energy – fusion of hydrogen to helium

A probable mechanism for the Sun’s fusion is called the *proton-proton chain*.

$$ {}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + {}^{0}_{1}e + \nu $$

$$ {}^{1}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + \gamma $$

$$ {}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + {}^{1}_{1}H + {}^{1}_{1}H $$



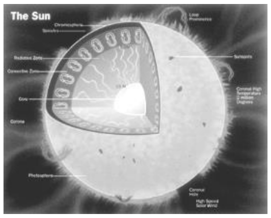
This chain is sometimes simplified to

$$ 4H \rightarrow He + energy $$

1. If the total mass of four hydrogen nuclei is 6.693 x 10^{-27} kg and the mass of a helium nucleus is 6.645 x 10^{-27} kg, determine the energy released in this simplified fusion reaction.

4.3 x 10^{-12} J

2. The Sun has a radius *R* of 7.0 x 10^{8} m and emits energy at a rate of 3.9 x 10^{26} W. The nuclear reactions take place in the spherical core of the Sun of radius 0.25*R*. Determine the number of nuclear reactions occurring per cubic meter per second in the core of the Sun.



4.1 x 10^{12} m^{-3} s^{-1}

Artificially induced fusion:
Attempts have been underway since the 1950s to build fusion reactors. Experimental reactors have come very close to producing more energy than the amount of energy put in, but a commercial fusion reactor has yet to be built.

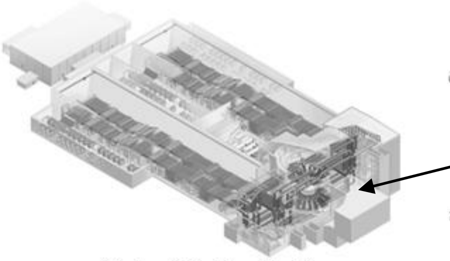
Plasma: The fuel for a fusion reactor is known as a *plasma*. This is a high energy ionized gas in which the electrons and nuclei are separate. If the energy is high enough (that is, the plasma is hot enough), nuclei can collide fast enough to overcome Coulomb repulsion and fuse together. Heating the plasma to the required temperatures (10 million K) is challenging. The nuclei, since they are charged, are accelerated by means of magnetic fields and forces to high kinetic energies (high temperatures).

Magnetic confinement: These charged particles are contained via magnetic fields and travel in a circle in a doughnut shaped ring called a "tokamak" which an acronym of the Russian phrase for "toroidal chamber with magnetic coils" (***to****roidal'naya* ***ka****mera s* ***ma****gnitnymi* ***k****atushkami*).

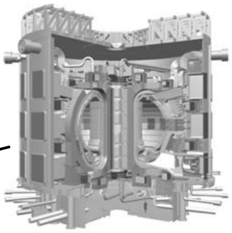
Problems with current fusion technology:

- Maintaining and confining these very high-density and high-temperature plasmas for any length of time is very difficult to do.

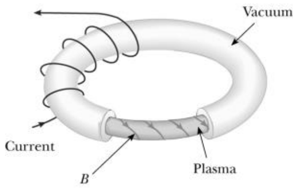
- Experimental reactors that currently can achieve fusion use more energy input than output which makes them not commercially efficient.



National Ignition Facility



Cut-away view of a tokamak



Inside a tokamak

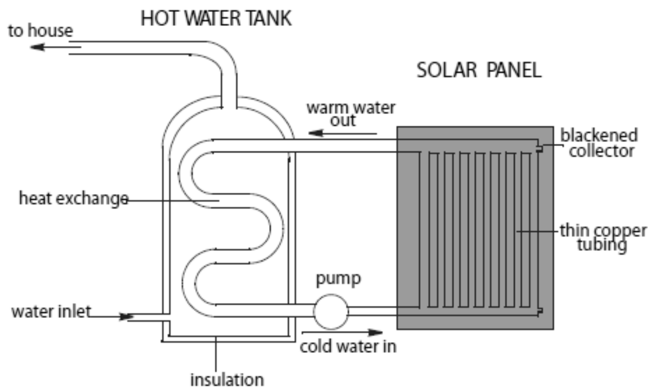
Comparison of Nuclear Fission and Nuclear Fusion

Nuclear fission	Nuclear Fusion
Splitting of a heavy nucleus into two or more light nuclei	Combination of two light nuclei to form a heavy nucleus
Takes place at room temperature	Requires a very high temperature equal to 4 X 10^{6} ^{o}C
Comparatively less amount of energy is released	Enormous amount of energy is released
Fission reaction can be controlled and the energy released can be used to generate electricity	Fusion reaction cannot be controlled and hence the energy released cannot be used to generate electricity
It is a chain reaction	It is not a chain reaction
It leaves behind radioactive wastes	It does not leave behind any radio active wastes

Solar Power

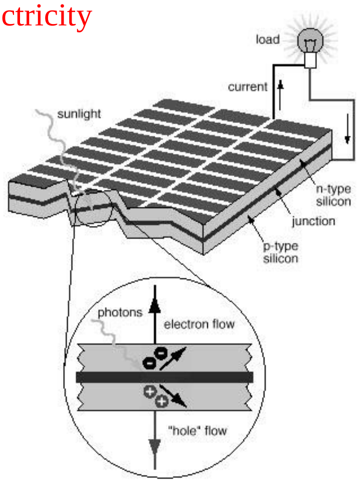
Solar heating panel (active solar heater): converts light energy from Sun into thermal energy in water run through it

Use: heating and hot water



Photovoltaic cell (solar cell): converts light energy from Sun into electrical energy

Use: electricity



Advantages of solar heating panel over solar cell: requires less (storage) area, less cost, more efficient

The amount (intensity) of sunlight varies with:

a) time of day

b) season (angle of incidence of sunlight – altitude of Sun in sky – Earth's distance from Sun)

c) length of day

d) latitude (thickness of atmosphere)

Which way should a solar panel or cell be facing in the Northern hemisphere? Why?
South to receive Maximum radiation from the sun to provide maximum energy for whole day

Advantages:	**Disadvantages:**
1. Renewable source of energy	1. Large area needed to collect energy
2. Source of energy is free	2. Only provides energy during daylight
3. No global warming effect – no CO_2 emissions	3. Amount of energy varies with season, location and time of day
4. No harmful waste products	4. High initial costs to construct/install

1. An active solar heater whose efficiency is 32% is used to heat 1400 kg of water from 20^0 C to 50^0 C. The average power received from the Sun in that location is 0.90 kW per m^2.

   a) How much energy will the solar heater need to provide to heat the water?

   b) How much energy will be needed from the Sun to heat the water?

   c) Calculate the area of the solar heater necessary to heat the water in 2.0 hours.

2. A photovoltaic cell with an area of 0.40 m^2 is placed in a position where the intensity of the Sun is 1.0 kW/m^2.

   a) If the cell is 15% efficient, how much power does it produce?

   b) If the potential difference across the cell is 5.0 mV, how much current does it produce?

   c) Compare placing 10 of these solar cells in series and in parallel.

Wind Power

Basic features of a horizontal axis wind turbine:

a) Tower to support rotating blades.

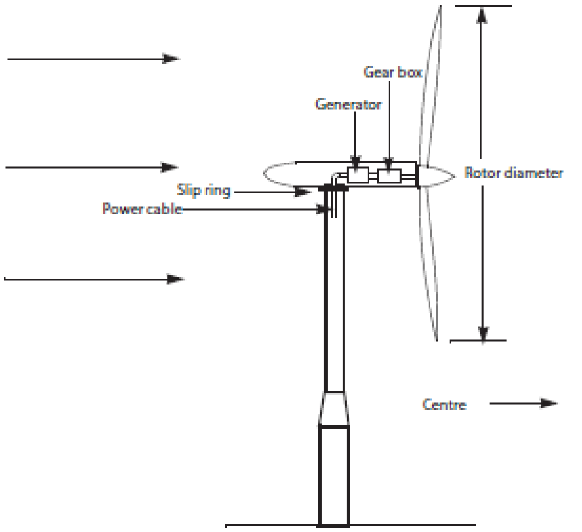
b) Blades that can be rotated to face into the wind.

c) Generator.

d) Storage system or connection to a distribution grid.

Energy transformations:

Solar energy heating Earth . . . Kinetic energy of air . . . kinetic energy of turbine . . electrical energy



Horizontal axis wind turbine

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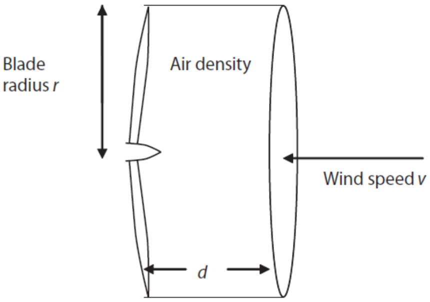
1. Determine the power delivered by a wind generator:



$$P = \frac{KE}{t} = \frac{1/2mv^2}{t}$$

$$P = \frac{1}{2}\left(\frac{m}{t}\right)v^2$$

$$P = \frac{1}{2}\left(\frac{\rho V}{t}\right)v^2$$

$$P = \frac{1}{2}\left(\frac{\rho A d}{t}\right)v^2$$

$$P = \frac{1}{2}(\rho v)v^2$$

$$P = \frac{1}{2}A\rho v^3$$

2. Reasons why power formula is an estimate:
   - a) Not all KE of wind is transformed into mechanical energy
   - b) Wind speed varies over course of year
   - c) Density of air varies with temperature
   - d) Wind not always directed at 90^0 to blades

3. Why is it impossible to extract this maximum amount of power from the air?
   - a) Speed of air cannot drop to zero after impact with blades
   - b) Frictional losses in generator and turbulence around blades

4. Why are turbines not placed near one another?
   - a) Less KE available for next turbine
   - b) Turbulence reduces efficiency of next turbine

1. A wind turbine has a rotor diameter of 40 m and the speed of the wind is 25 m/s on a day when the air density is 1.3 kg/m^3. Calculate the power that could be produced if the turbine is 30% efficient.

$\text{Power} = ½\ A\ \rho\ v^3 \text{ and } A = \pi r^2$

$= 0.3 \times 0.5 \times \pi \times 10^2\ m^2 \times 1.3\ kgm^{-3} \times 25^3\ m^3s^{-3}$

$= 9.57 \times 10^5\ W$

2. A wind generator is being used to power a solar heater pump. If the power of the solar heater pump is 0.50 kW, the average local wind speed is 8.0 m/s and the average density pf air is 1.1 kg/m^3, deduce whether it would be possible to power the pump using the wind generator.

$\text{Power} = ½\ A\ \rho\ v^3 \text{ and } A = \pi r^2$

$500\ Js^{-1} = 0.5 \times \pi \times r^2\ m^2 \times 1.1\ kgm^{-3} \times 8.0^3\ m^3s^{-3}$

$r = \sqrt{2P / \pi\rho v^3}\ \sqrt{1000 / \pi \times 1.1\ kgm^{-3} \times 512\ m^3s^{-3}}$

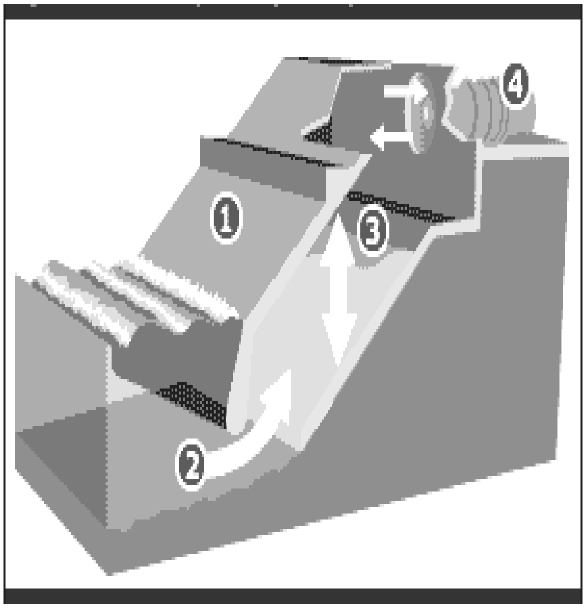
$= 0.23\ m$

This is a small diameter so it could be feasible provided the wind speed was always present.

Advantages:	**Disadvantages:**
1. Renewable source of energy	1. Large land area needed to collect energy since many turbines are needed
2. Source of energy is free	2. Unreliable since output depends on wind speed
3. No global warming effect – no CO_2 emissions	3. Site is noisy and may be considered unsightly
4. No harmful waste products	4. Expensive to construct

Wave Power

Energy can be extracted from water waves in many ways. One such scheme is shown here.



Oscillating Water Column (OWC) ocean wave energy converter:

1. Wave capture chamber is set into rock face on land where waves hit the shore.
2. Tidal power forces water into a partially filled chamber that has air at the top.
3. This air is alternately compressed and decompressed by the "oscillating water column."
4. These rushes of air drive a turbine which generates electrical energy.

Energy transformations:

Kinetic energy of water . . . Kinetic energy of air . . . kinetic energy of turbine . . electrical energy

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Determining the energy in each wavelength of the wave and the power per unit length of a wavefront

Energy in each wavelength of the wave

$PE = mgh$

$PE = mgA$

$PE = (\rho V)gA$

$PE = (\rho(\frac{1}{2}\lambda AL))gA$

$PE = \frac{1}{2}A^2\lambda g\rho L$

power

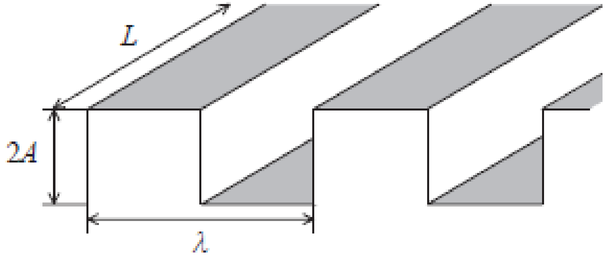
$P = \frac{PE}{t}$

$P = \frac{\frac{1}{2}A^2\lambda g\rho L}{T}$

$P = \frac{1}{2}A^2 v g\rho L$

power per unit length

$\frac{P}{L} = \frac{1}{2}A^2 v g\rho$



How would this power estimate change if the waves were modeled as sine waves instead of square waves?

1. Waves of amplitude 1.5 meter roll onto a beach with a speed of 10 m/s. Calculate:

   a) how much power they carry per meter of shoreline

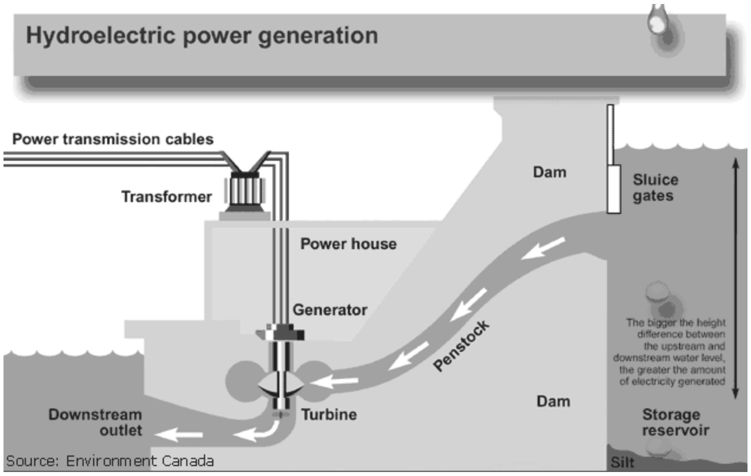
   b) the power along a 2 km stretch of beach.

2. Waves that are 6.0 meters high with a 100 meter wavelength roll onto a beach at a rate of one wave every 5.0 seconds. Estimate the power of each meter of the wavefront.

Advantages:	**Disadvantages:**
1. Renewable source of energy	1. Can only be utilized in particular areas
2. Source of energy is free	2. High maintenance due to pounding of waves
3. No global warming effect – no CO_2 emissions	3. High initial construction costs
4. No harmful waste products	

Hydroelectric Power

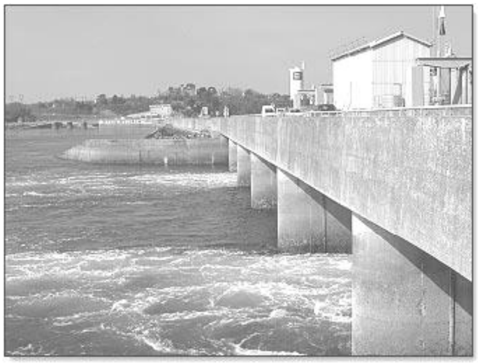
There are many schemes for using water to generate electrical energy. But all hydroelectric power schemes have a few things in common. Hydroelectric energy is produced by the force of falling water. The gravitational potential energy of the water is transformed into mechanical energy when the water rushes down the sluice and strikes the rotary blades of turbine. The turbine's rotation spins electromagnets which generate current in stationary coils of wire. Finally, the current is put through a transformer where the voltage is increased for long distance transmission over power lines.



Source: Environment Canada

By far, the most common scheme for harnessing the original gravitational potential energy is by means of **storing water in lakes**, either natural or artificial, behind a dam, as illustrated in the top picture at right.

A second scheme, called **tidal water storage**, takes advantage of big differences between high and low tide levels in bodies of eater such as rivers. A barrage can be built across a river and gates, called sluices, are open to let the high-tide water in and then closed. The water is released at low tide and, as always, the gravitational potential energy is used to drive turbines to produce electrical energy.



A third scheme is called **pumped storage.** Water is pumped to a high reservoir during the night when the demand, and price, for electricity is low. During hours of peak demand, when the price of electricity is high, the stored water is released to produce electric power. A pumped storage hydroelectric power plant is a net consumer of energy but decreases the price of electricity.

Energy transformations:

Gravitational PE of water . . . Kinetic energy of water . . . kinetic energy of turbine . . electrical energy

Advantages:

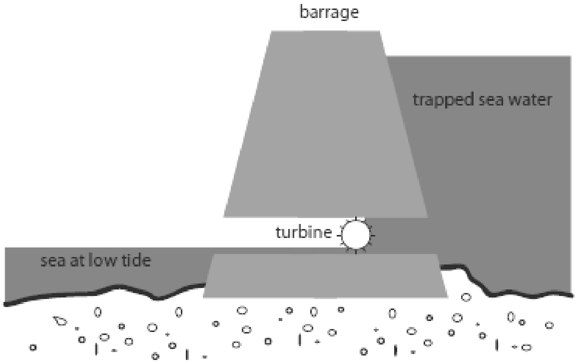
1. Renewable source of energy
2. Source of energy is free
3. No global warming effect – no CO_2 emissions
4. No harmful waste products

Disadvantages:

1. Can only be utilized in particular areas
2. Construction of dam may involve land being buried under water
3. Expensive to construct

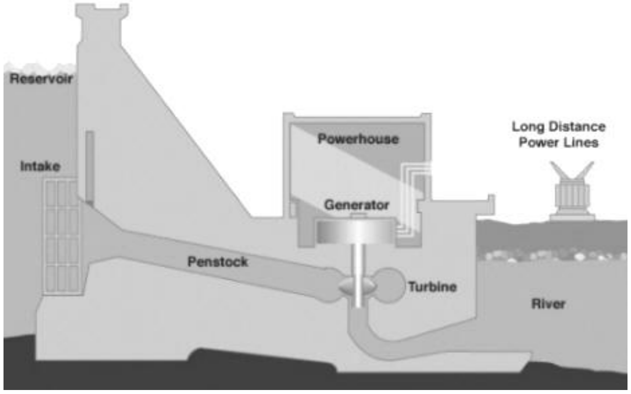
1. A barrage is placed across the mouth of a river at a tidal power station. If the barrage height is 15 meters and water flows through 5 turbines at a rate of 100 kg/s in each turbine, calculate the power that could be produced if the power plant is 70% efficient. 2.6×10^4W

   Use average height for $E_P = mgh$



2. A reservoir that is 1.0 km wide and 2.0 km long is held behind a dam. The top of this artificial lake is 100 meters above the river where the water is let out at the base of the dam. The top of the intake is 25 meters below the lake's surface. Assume the density of water is 1000 kg/m^3.

   a) Calculate the energy stored in the reservoir.
   4.3×10^{13} J



   b) Calculate the power generated by the water if it flows at a rate of 1.0 m^3 per second through the turbine.
   875 kW