Renewable Energy

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Objectives

- Provide students with an overview of the current energy issue
- Introduce various renewable energy technologies

Learning Outcome

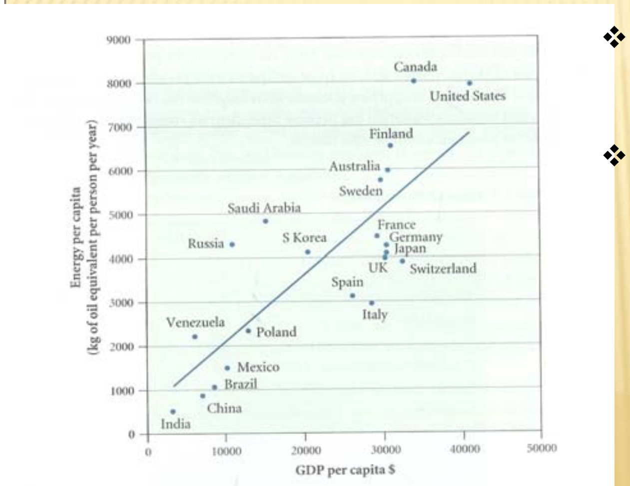
- Upon completion of the subject, students will be able to:
  - Apply knowledge in renewable energy to the future development of Green Society.
  - Be aware of the rapidly changing technology and be ready to adapt to new knowledge via self-learning and life-long learning

Contents

- *Introduction*
  - Global Energy Trends
  - Basic Principles
  - Existing Technology
- *Renewable Energy Technologies*
- *Hydrogen Economy*
- *Why are the Renewable Energies still not common among Nations?*
- *Conclusion*

Global Energy Trends

- Strong correlation between the energy consumption per capita and standard of living (GDP per capita) (2008).



❖ Larger GDP per capita, more energy per capita

❖ Increasing GDP per capita for China, Brazil and India, more energy will be needed

Current Consumption

- In 2008, total worldwide energy consumption was 474 exajoules (5×10^{20} J) with 80 to 90 percent derived from the combustion of fossil fuel.
- Equivalent to an average power consumption rate of 15 terawatts (1.5×10^{13} W).
- 5% increase : 750×10^{9} W

(Three Gorges Dam Project: 18.2 million kilowatts i.e. 42 Dam)

- New sources & reduced usage

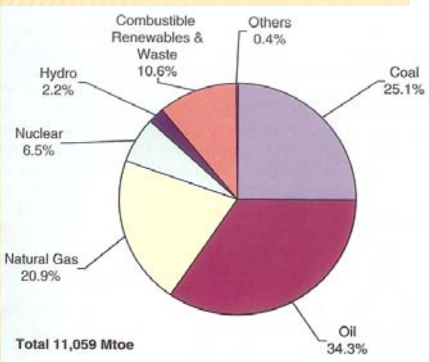
Reserve

- **Primary Energy**: derived directly from nature – fossil fuel, renewable energy
- **Secondary**: Electricity, gasoline.

Table III: World Energy Resources and Availability.

Resource	Energy Potential (TWy)
Oil and gas (conventional)	1,000
Oil and gas (unconventional)	2,000
Coal	5,000
Methane clathrates	20,000
Oil shale	30,000
Uranium (conventional)	370
Uranium (breeder)	7,400
Sunlight on land	30,000 per year
Wind	2,000 per year
Fusion (if successful)	250,000,000,000

Source: Reference 57 for uranium and Reference 4 for all other resources.
Note: Current world energy use is about 15 TWy per year.



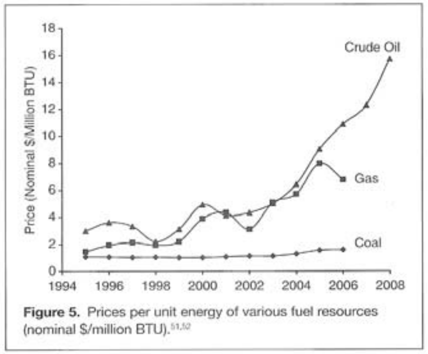
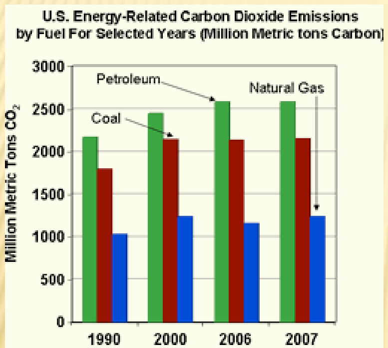


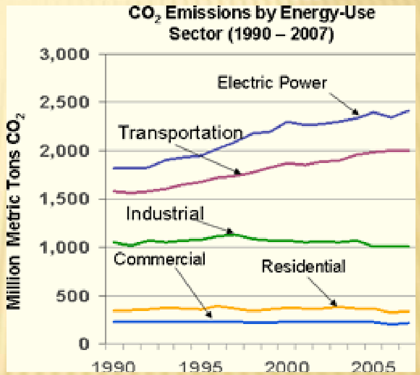
Figure 5. Prices per unit energy of various fuel resources (nominal $/million BTU).[51,52]

- Fossil fuel - oil, coal, and gas represent about 80% of all primary energy production in 2008
- Reserve in energy by fuel type

  Oil - 40 years, Gas – 70 years, Coal – 250 years

CO_2 Emission





Present Situation

- *Problems?*

- *Solution?*

Basic Principles

Basic forms of Energy : Potential Energy (位能)
Kinetic Energy (動能)

- Springs and elastic bands (PE<=>KE)

Other Forms:

Chemical: Food
Burning fuels, oil, natural gas, gasoline, diesel, wood
Battery

Light: Lasers
Light radiant energy, in the form of photons by the sun
Fluorescent and incandescent light bulbs or light-emitting diodes

Thermal: conduction(傳導), convection (對流) , radiation (輻射)
Energy of moving particles (atoms and molecules) of liquid, gas, or solid matter
Earth's core, provide usable heat from ground sources (e.g., hot springs)
Melting and shaping materials such as metal and plastic

Electrical: Running computers,
Electricity moving through a conductor
Photovoltaic panels
Alternator or dynamo generators
Hydrogen fuel cells
Friction (static electricity)

Mass: nuclear energy (fussion, fission) $E = mc^2$

- **Law of Conservation of Energy: Energy cannot be destroyed or created**

- **Energy can be converted from one form to another form.**
  - Electricity passing through a heating element to heat air and water in homes and offices (electrical to thermal)
  - Cooking in microwave ovens (radiant to thermal)
  - Hydro-electricity facilities (mechanical to electrical)

Basic Principles: Basic units

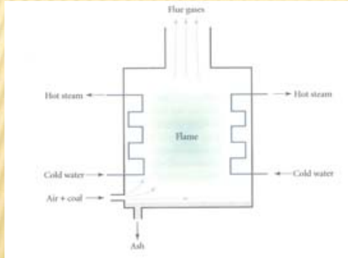
Quantity	*Unit*	*Definition*
Force	Newton(N)	Force required to accelerate 1 kg by 1 m/s
Energy	joule (J)	Workdone by 1 N force in moving 1 kg by 1m
	calorie	Energy required to heat 1 g of water by 1ºC (4.2 J)
	kilowatt-hour	3.6×10^6 J or 860 kcal
	Btu	1 lb of water by 1ºF (1.06 kJ)
Power	Watt (W)	1 J/s
	horsepower	0.746 kW

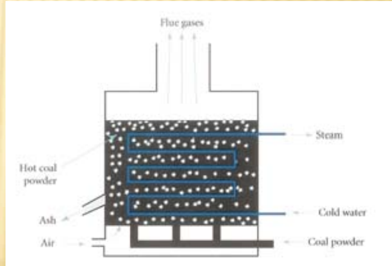
Fuel Equivalence : 1 tonne oil = 1.5 tonnes hard coal = 3.0 tonne lignite = 12 000 kWh

Unit Prefixes: exa =one billion billion (10^{18}), peta=one million billion (10^{15}), tera =one million million (10^{12}), giga =one billion (10^9)

Existing Technology: Coal Plant

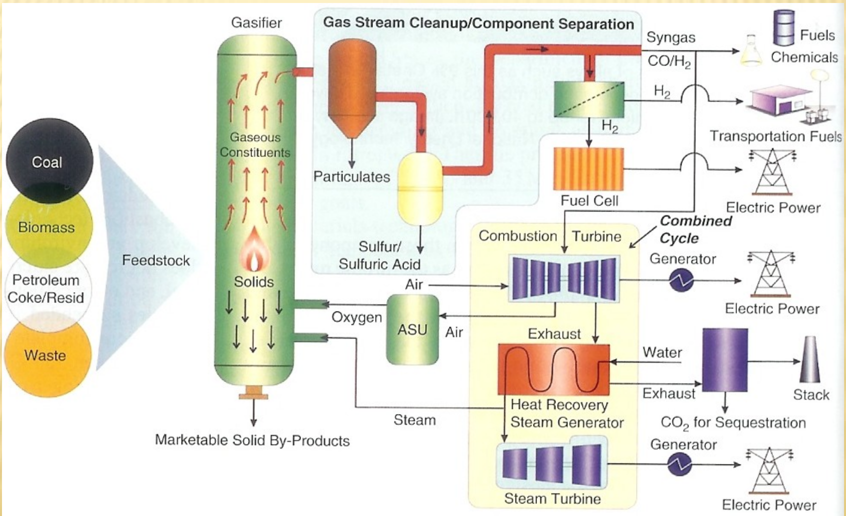
- Main source of Electricity Generation
  - Cheap (5¢/kWh), 50% in USA, 80% in China
  - Pollution: CO_2, SO_2, NO_x
  - Inject CO_2 into ground, react with mineral to form carbonate, trap in ice (carbonic acid) and settle down on sea floor



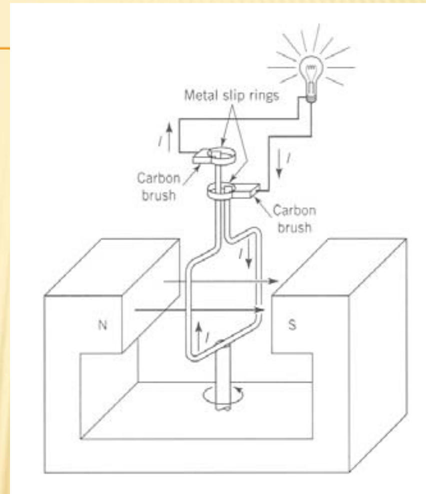


- Coal-fired combustion chamber Fluidized bed

•Schematic of a gasification-based system for production energy from coal and other carbon-based feedstocks.

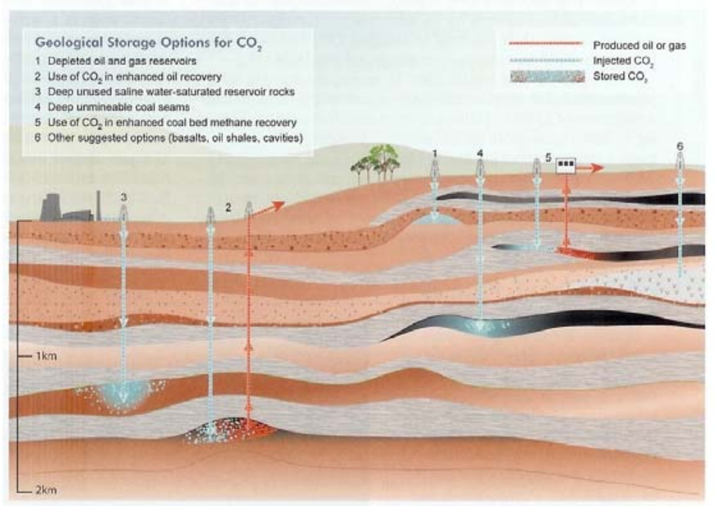


- An elementary AC generator. A loop of wire is forced to rotate in a magnetic field. The induced AC enters the external circuit through contacts that rub against rotating metal rings attached to the coil. The current generated reverses in direction as the coil rotates.



• Carbon Dioxide Capture and Storage (CCS)

•3 capture methods:
•Post-combustion: separates CO_2 from exhaust gas using monoethanolamine. Low efficiency(25%), cost ($40/tonne), easy for industry to adopt.
•Pre-combustion: fossil fuel gasified to syngas ($CO + H_2$), then used water-shift reaction to form pure hydrogen. Lower cost ($20/tonne), better efficiency
•Oxycombustion: combustion in pure oxygen environment to avoid the need to separate CO_2 from N_2 in the exhaust gas. Easy for industry to adopt. Limited experience. Higher temperature.



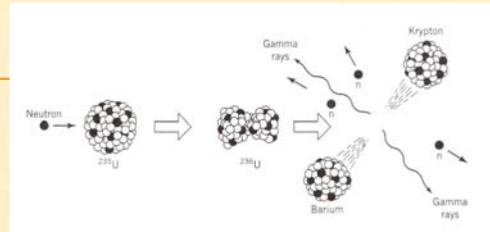
- 60% of CO_2 emission coming from point sources, great contribution.
- CCS contributes 20 % of needed CO_2 emission reductions.

• How long will the CO_2 remain trapped underground?
•Capillary trapping, dissolution in brine, adsorption on coal, mineral trapping.
• >99% over 1000 years.
•Storage in Ocean: at depth >350 m , soild CO_2, easily dissolved in water. Storage > 3 km to ensure the dissolved CO_2 is denser than water.
•Negative public opinion and biological impacts.

Existing Technology : Nuclear Energy

- Nuclear Energy is an energy released by the fission or fusion of the nuclei of atom
- France 78%, Japan 26%
- No CO_2 emission
- Safety: Three Miles Island (79)/Chernobyl (86)/Japan (11), waste disposal, weapons proliferation
- ^{235}U used as fuel with 50 years of operation

Nuclear Fission

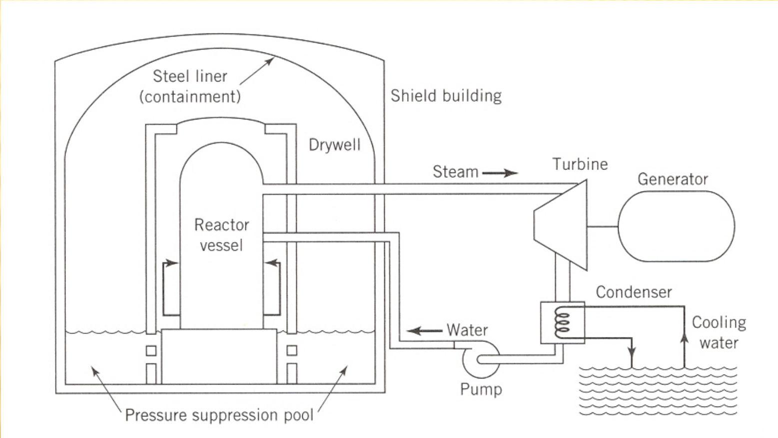


Splitting of large nuclei to two
→ loss in mass
→ lighter than original nucleus
→ missing matter has been converted into energy

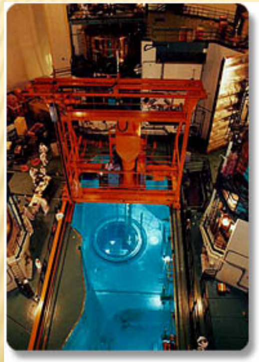
Uranium 235
→ common isotope
→ start fission
→ split into two by a neutron
→ releases energy and neutrons
→ continuous splitting by neutrons
→ Produce energy until no more splitting

Another choice
→ Plutonium 239
→ too dangerous, poisonous.

- Boiling water reactor power plant. Steam is produced in the reactor vessel and flows at high pressure to the turbine.



Guangdong Daya Bay Nuclear Power Station



Advantages of nuclear energy

- Small space: Smaller than other electrical plants with the same output of energy
- Low running cost: Uranium is cheaper than oil and coal, enhance job opportunity
- Lots of energy: More energy than burning fossil fuels
- No greenhouse gases: Carbon dioxide, Sulphur dioxide or flyash → Avoid pollution, greenhouse effect, acid rain, global warming
- Medical science: Nuclear medicine, Cancer therapy, CAT scan, MRI machines, irradiation of food.

Disadvantages of nuclear energy

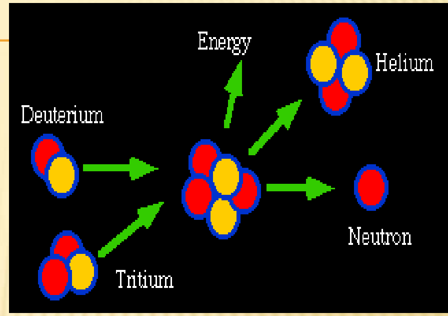
- High initial cost: Expensive to build up a nuclear plant, much more expensive than a fossil fuel plant
- Meltdown: Chain reaction, Uranium and nuclear waste are heated
  - Melt steel, concrete and iron,
  - damage the structure of nuclear plant
- High radioactive level of nuclear waste:
  - High energy emission, lethal
  - Difficult to storage, cannot be excreted to air or sea
  - Need to build up an extra plant for waste storage

Suggestions for Waste Disposal

- Low level waste
  - Solid: burial facilities
  - Liquid: mixed with concrete or urea formaldehyde to form a solid, then shipped to burial facilities
  - Gas: stored in tanks until its half life finish.
- High level waste
  - Imbedded in rock or salt form and bury far under the earth surface.

Nuclear Fusion

- Binding of multiple like-charged atomic nuclei together
- Form a heavier nucleus
- Achieved by the release or absorption of energy



Advantages of Fusion	*Disadvantages of Fusion*
No radioactive products Clean Energy	Extremely high temperature for fusion
Deuterium & Tritium Hydrogen isotopes Unlimited energy source	need 2 small nuclei able to fuse together and give off energy
Provide almost endless energy	Hard to capture the energy given off

Renewable Energy

•**Renewable energy** is energy generated from natural resources — such as sunlight, wind, rain, tides and geothermal heat — which are renewable (naturally replenished).

• In **2008**, about 19% of global final energy consumption came from renewable energy

- 13% coming from traditional biomass, such as wood-burning.
- hydroelectricity was the next largest renewable source, providing 3.2%
- Modern technologies, such as geothermal energy, wind power (2%), solar power, solar heating, ocean energy and biofuel provided 2.7% of final energy consumption

•In **2008**, about 18% of global electricity came from hydroelectricity (15%), others (3%).

•In **2008**, about 5% (68 billion liters) of gasoline replacement using biofuel

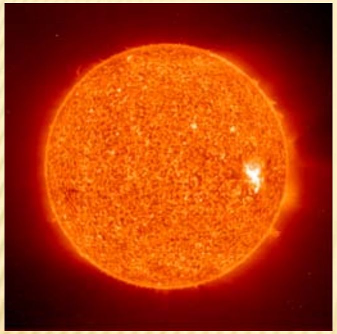
Renewable Energy

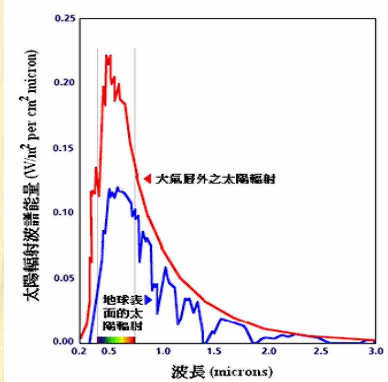
- Replacement:
  - Power generation
  - Hot water/space heating
  - Transport fuel
  - Rural (off-grid) source

- In 2009 : wind 158 GW, PV 21 GW

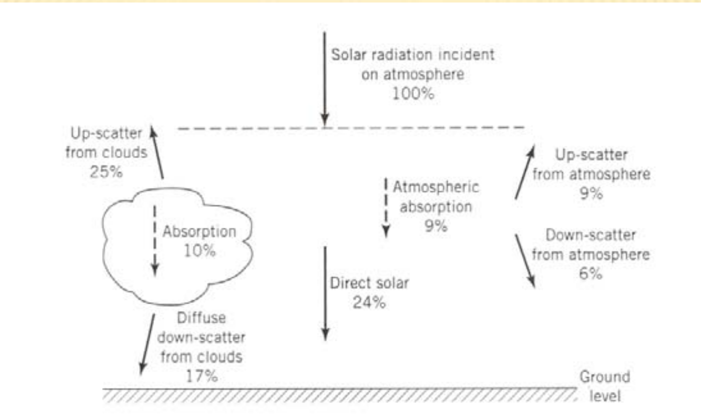
- Types of Renewable Energy
  - **Solar**
  - **Wind**
  - **Hydro-power**
  - **Ocean: Tides & Wave**
  - **Geothermal**
  - **BioEnergy**

Renewable Energy: Solar Energy





- Average solar power on Earth 100,000 TW (world consumption about 15 TW i.e. 1 hr of solar energy ≈ 10 months of world consumption)
- fossil fuel & biomass come from photosynthesis (solar energy)
- Efficiency of biomass (~ 0.2 – 2%), photovoltaic cells (15%).

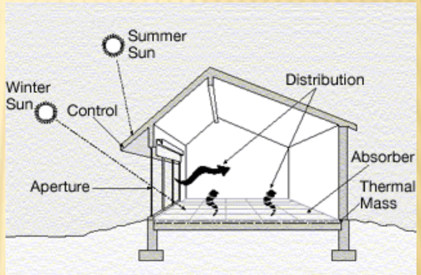


- Absorption and scattering of solar radiation in the atmosphere. The values shown are for average weather, over all seasons and latitudes.

Designs and Applications

- Thermal: radiation into heat energy for directly used
  - Thermal heating for buildings:

Passive type:
use glass as wall
to receive more
sunlight



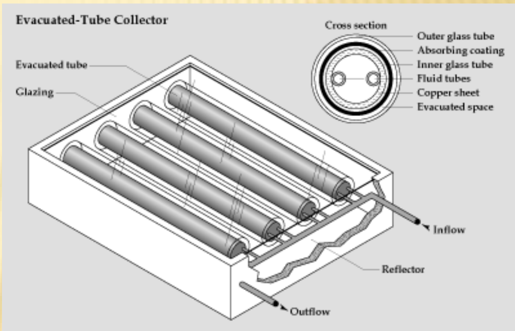
Passive type:
better design

Enforced type: use hollow metallic wall to use sunlight to heat up the buildings

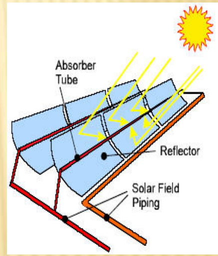
- Solar water disinfection system

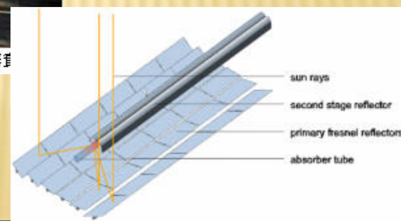
- Solar cooking system

- Solar Water Heater: working fluid is either pumped (active system) or driven by natural convection (passive system).



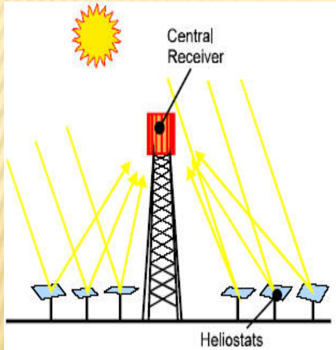
- Concentrating Solar Power (CSP):
  - Parabolic Trough Systems: long, rectangular curved mirrors, heating oil flowing through the receiver, hot oil used to boil water in steam engine

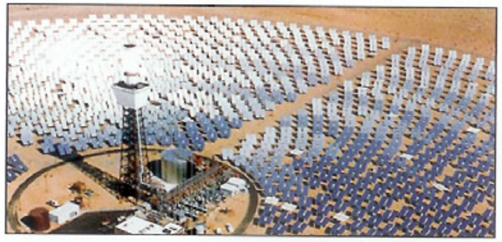




- Concentrating Solar Power (CSP):
  - Dish/engine system: uses mirrored dish (satellite dish) to collect solar energy, made of metallized glass or plastic, heat up fluid (hydrogen or helium) to 700°C/200 MPa, Stirling engine (pistons, 40% efficiency) or turbine.

- Concentrating Solar Power (CSP):
  - Power Tower system: large field of mirrors, molten salt as working fluid, generates steam for steam engine.



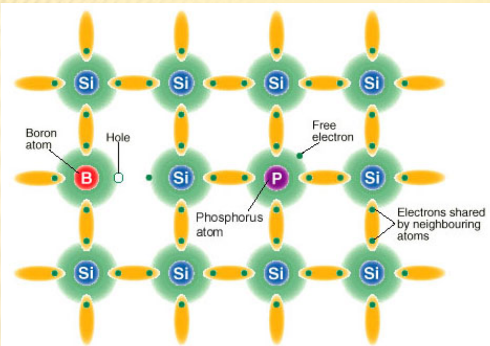


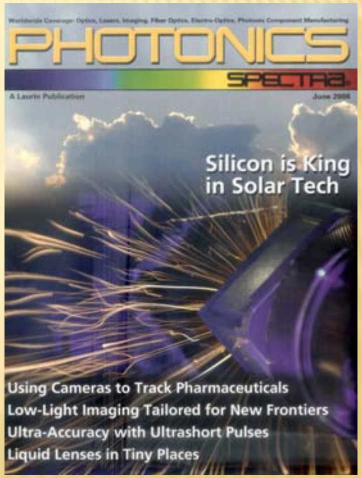
Solar 2 power tower in Barstow, California. The plant uses a combination of 60% sodium nitrate and 40% potassium nitrate as a working fluid and heat storage medium.

High efficiency 15 – 20%, high cost (5 times of coal plant), large area needed.

Photovoltaics (PV)

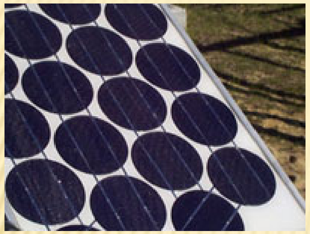
- materials directly convert radiation into electricity





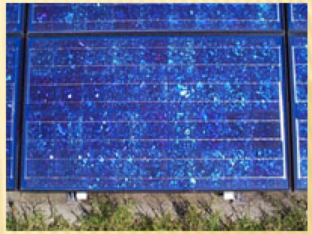
- Semiconductors - Si

Different forms of Si PV Cells



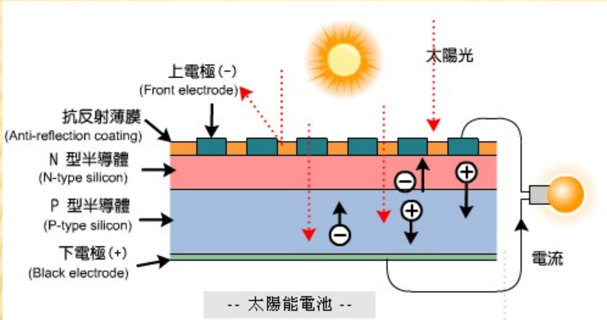
Single crystal Si單晶矽(14 to 19%)

Polycrystalline Si多晶矽(13 to 17%)



Amorphous Si非晶矽(6 to 8%)

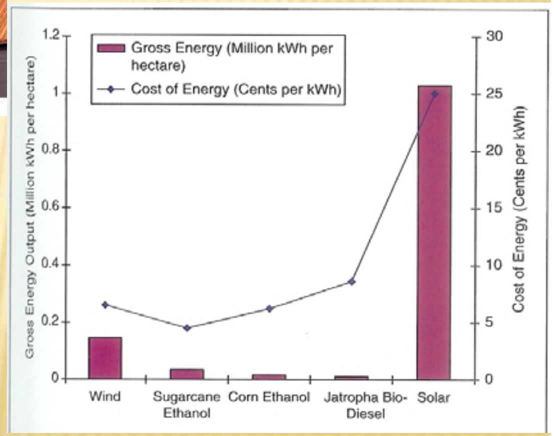
Working principle for PV cell



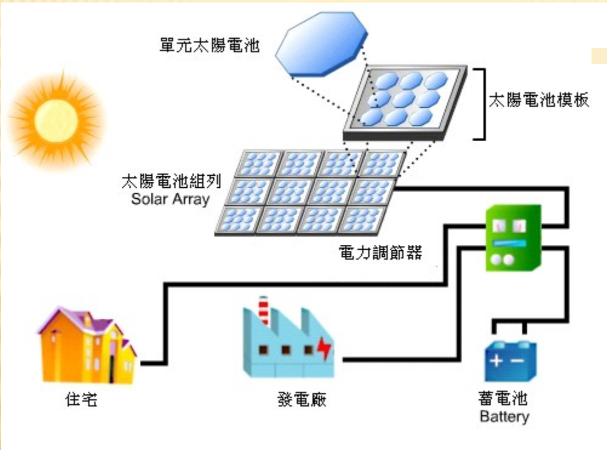
•PV cells: 2.5 GW (2004) to 1000 GW (2030)

• Si - ideal efficiency 23% - lost due to heat generated (30%), not absorbed (energy gap of Si is 1.1 eV, 25%), recombination of electron-hole pairs (10%) , reflection from surface.

Applications of PV panels: domestic use



PV System



- PV array, PV controller, battery.
  - *Stand-Alone* 獨立型
  - *Grid-connected* 併聯型

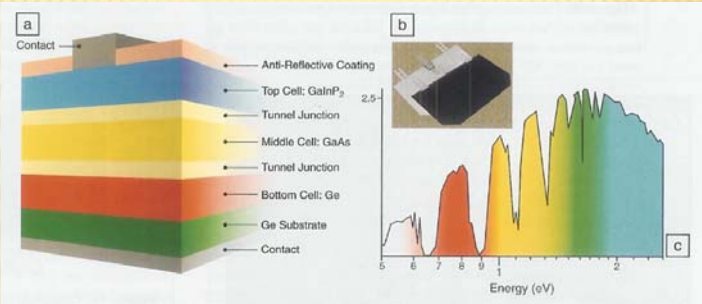
Future Developments of PV Cells

- 1st generation: crystalline Si, large grain polycrystalline Si. Ribbon-based technologies from molten Si (lower material costs)

Thinner (30 μ m) compared to single crystalline (300 μ m).

No cutting process.

- 2nd generation:
  - solar thermal conversion,
  - thin film PV cell (CdTe, $Cu(InGa)Se_2$, a-Si) –cheap with high efficiency
  - solar concentrator based on GaAs PV cell – expensive with extremely high efficiency (theoretical: 60%).



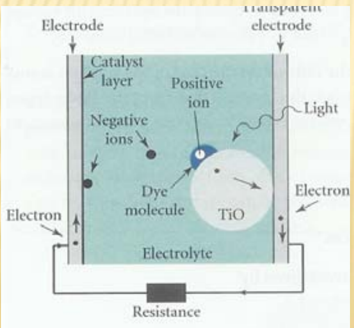
(a) Schematic of a possible configuration for a three- (triple-) junction device.

(b) GaInP/GaAs/GaInAs cell (40%)

(c) Solar spectrum showing the spectrum splitting by a multi-junction cell. (>60%)

- 2nd generation:
  - organic photovoltaic cell – polymer-based PV materials on polymer substrates, high flexibility, existing LED/display technologies, very cheap in manufacturing and material, efficiency 5%, integrated into existing buildings

- 3rd generation: Ultimate thin film solar cell – high efficiency, use of abundant nontoxic and durable material.
  - Multi-junction cell: nano-Si quantum dots in silicon oxide or nitride matrix. (theoretically 70%)
  - Upconvertion: two low energy photons combined to form a higher energy photon.
  - Electrochemical cells: dye-sensitized solar cells (DSSC)



Thermoelectric

- Discovered in 1800 by Seebeck. Two dissimilar materials are held at different temperature, a voltage is generated. A significant temperature difference can generate electrical energy.
- The process is quite simple. Easy maintenance (no mechanical parts), long-term stability.
- Radioisotope thermoelectric generators (RTG) used in deep-space mission.
- Waste-heat-recovery technologies: automobiles (60% fuel energy lost as waste heat), industrial furnaces and power plant.
- Challenge: materials (good electrical conductor and poor thermal conductor, phonon-glass-electron-crystal) needed - superlattices, quantum dot, nanodot bulk material.

• Hybrid system applications:

	Wavelenth	Spectrum	%
Photovoltaic	~200–800nm	UV & visible light	58
Thermoelectric	~800–3000nm	IR	42

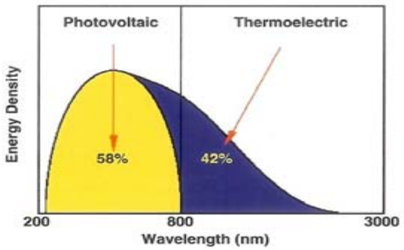
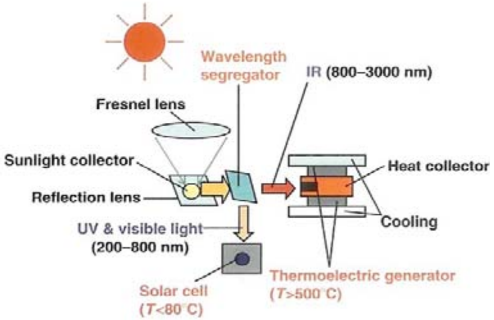


Figure 2. Sun radiates energy as a 6000 K blackbody radiator with part of the energy in the ultraviolet (UV) spectrum and part in the infrared (IR) spectrum.



- Solar energy harvesting: TE works in tandem with other energy technologies, especially solar PV cells.

Return

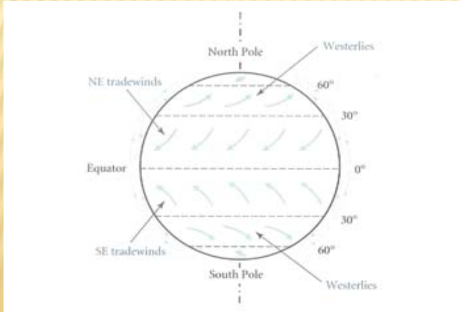
Renewable Energy: Wind Energy

•Source: solar ⟹ absorbed by land & sea ⟹ heat surrounding air ⟹

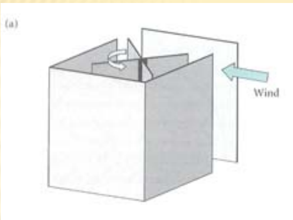
•Materials absorb radiation differently ⟹ temperature gradient pressure gradient ⟹ wind

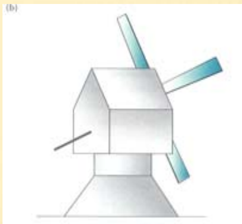
•Produce 10 – 20 % of the electrical power currently used

•Wind power ~ 1 – 2% of the incident solar power (total ~ 10^{15} W)



•10th century in Persia, 1st recorded use - vertical axis windmills (a)

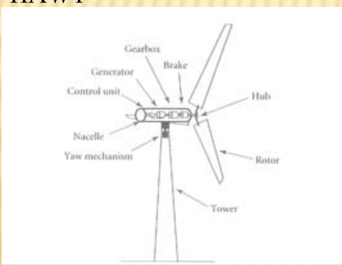




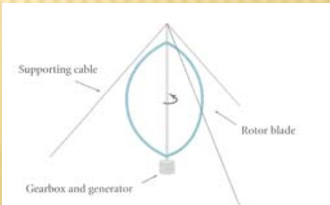
•12th century in Europe - horizontal axis windmills (b) post-mills & tower-mills

•1930's to 1960's – wind turbines: horizontal-axis wind turbines (HAWTs), vertical – axis wing turbines (VAWTs)

HAWT



VAWT



•VAWT: no yaw mechanism, easier to maintain, height limited

HAWT: cost effective, greater height (90 m with blades 68 m) & stronger wind (5 MW)

•Wind Power = ½ A ρ u^3, where A(area), ρ (air density), u (speed)

•HAWT: max. efficiency = 59% (Lanchester-Betz Limit)

Modern design: (1) large tip-speed ratio (speed of the blade at the tip/speed of the incident wind), high shaft speed and low torque, small generator, thinner blade (2) larger turbines with higher hubs, reduce maintenance cost & land cost

❖Adv. : green energy, no global warming, no pollution,

❖Disadv. : unstable & unpredictable, visual impact (offshore installation, higher cost), threat to bird (0.13 birds/turbine; 57 millions by car, 97 millions by plane per year), large area for wind farm, noise.

Applications

•Wind turbines >> electricity

•Wind mills >> mechanical power

• Wind pump >> drainage/agriculture

• Sails >> transport

•Estimated potential 72 TW. In 2010, total generation 175 GW.

•Current turbines: 600 kW to 5 MW (commercial: 1.5 to 3 MW) with capacity factor 20% to 40%.

•Payback time: energy (few months), CO_2 (2.5yr)

Challenge

❖Offshore installation: demanding environmental condition, high cost

❖ Larger blades: huge wind and gravitational loading

❖ Fiber-reinforced polymers as blade materials, low tensile strength and shear strength along out-of-plane direction, low recyclability

❖ Lifecycle energy balance energy required for the combined installation and end-of-life disposal phases is 6 – 12 months of operation (lifetime 20 years). Energy yield factor = 20 to 40.

❖ Electrical storage: deliver power according to wind speed, not demand.

❖Future: supplementary to the main grid (~ 20 %)

Wind maps of Western Europe

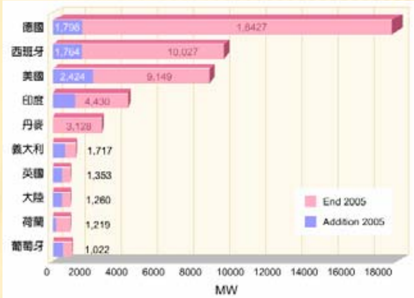
- Important in planning.

Wind Resources at 50 (45) m above Ground Level

Color	Sheltered terrain m/s	Sheltered terrain W/m²	Open plain m/s	Open plain W/m²	At a sea coast m/s	At a sea coast W/m²	Open sea m/s	Open sea W/m²	Hills and ridges m/s	Hills and ridges W/m²
	>6.0	>250	>7.5	>500	>8.5	>700	>9.0	>800	>11.5	>1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0-8.5	400-700
	<3.5	<50	<4.5	<100	<5.0	<150	<5.5	<200	<7.0	<400
			>7.5							
			5.5-7.5							
			<5.5							

Future of Wind Power

- Germany :3% to 5% of the total power



- Lightweight railway powered by wind energy

Return

Renewable Energy: Hydropowder

- Hydropower, hydraulic power or water power is power that is derived from the force or energy of moving water, which may be harnessed for useful purposes.
- irrigation(灌溉), operation of various machines, such as watermills, textile machines, sawmills(鋸木廠), and domestic lifts.
- creation of hydroelectricity. The amount of water power :
- Water Power = Head x Flow x Gravity x Density

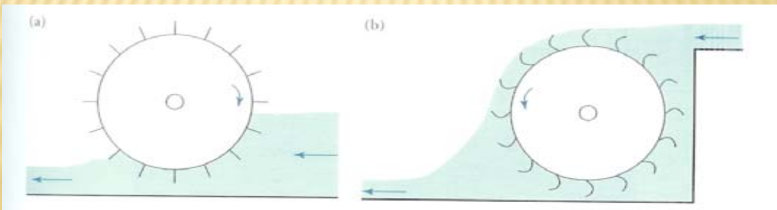
"Water Power" is given in watts "Head" is given in metres

"Flow" is the volumetric rate at which water is moving through the pipe, in cubic metres per second

"Gravity" is the acceleration due to gravity and is approximately equal to 10 metres per second-squared

"Density" is the density of water and is approximately equal to 1000 kg per cubic metre

- Solar energy ⟹ sea water evaporation ⟹ rainfall ⟹ rivers ⟹ sea
- Accounts for about 2% of global electricity
- Ancient world for irrigation, grinding corn, metal forging, mining
- (a) Undershot and (b) overshot waterwheels



Ten of the largest hydroelectric producers as at 2009

Country	Annual hydroelectric production (TWh)	Installed capacity (GW)	Capacity factor	% of total capacity
China	652.05	196.79	0.37	22.25
Canada	369.5	88.974	0.59	61.12
Brazil	363.8	69.080	0.56	85.56
United States	250.6	79.511	0.42	5.74
Russia	167.0	45.000	0.42	17.64
Norway	140.5	27.528	0.49	98.25
India	115.6	33.600	0.43	15.80
Venezuela	85.96	14.622	0.67	69.20
Japan	69.2	27.229	0.37	7.21
Sweden	65.5	16.209	0.46	44.34

- 1936 Hoover Dam (USA) 1345 MW

•1942 Grand Coulee Dam (USA) 6809 MW

•1984 Itaipu Dam (Brazil) 14000 MW

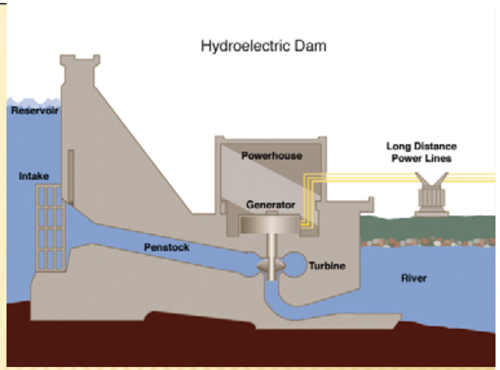
•2008 Three Gorges Dam (China) 22500 MW

Types of Hydroelectric Stations

- Micro hydro - hydroelectric station with installed capacity lower than 100 kW
- Mini hydro - hydroelectric station in the range of 100kW to 1 MW
- Small hydro - hydroelectric station in the range of 1 MW to 30 MW
- Large hydro - hydroelectric station with installed capacity of over 30 MW

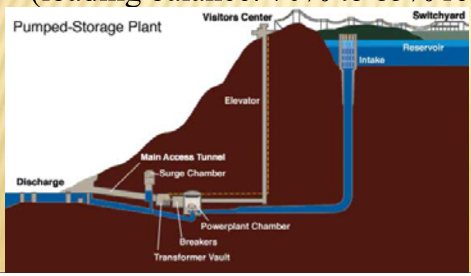
•***Types***:

•Conventional



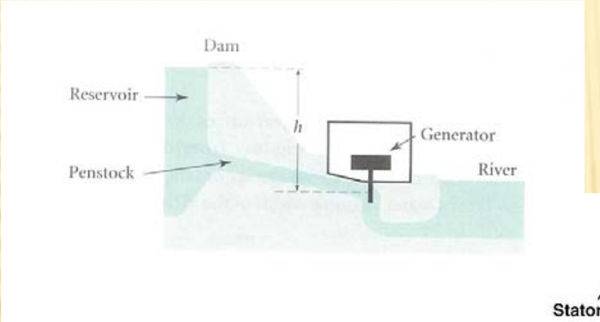
•Pumped-storage

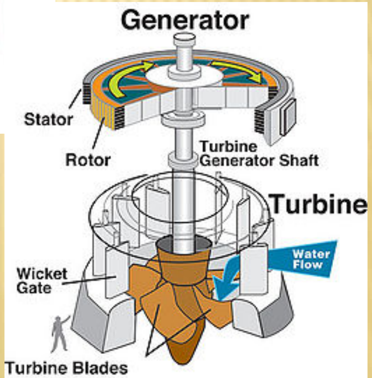
(loading balance: 70% to 85% recover)



- Run-of-the-river (Washington, USA)
- Underground (Northern Quebec)

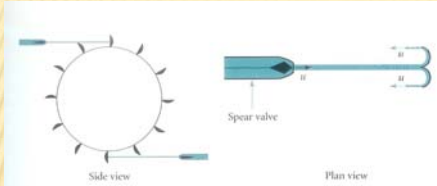
- Reservoir & generator: convert potential energy into



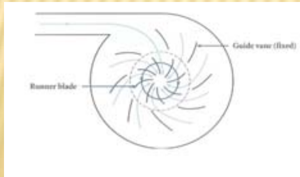


Water Turbine

- Two main types of water turbine:
  - Impulse (Pelton wheel): changes the velocity (momentum → impulse/force) of the water jet.



  - Reaction: acted by water, changes pressure as it moves through the turbine (suction) and gives up its energy



Advantages

❖ no greenhouse/acid rain gases

❖ low production, operation and maintenance costs (40 to 100 yrs), cost of dam operation can be offset within 8 yrs, long economic lives

❖ eliminate of the cost of fuel

Disadvantages

❖ risk of major accident, high cost (construction, decommission)

❖ poor water quality

❖ effect on environment, disruptive to surrounding aquatic ecosystem both upstream and downstream

❖ Population relocation

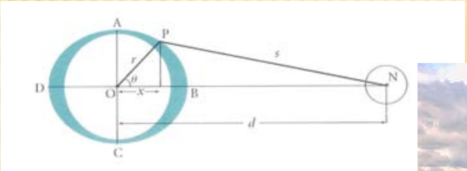
Some Hydro-related Installations in Hong Kong

Year of Installation	Organization	Venue of Installation	Type of Installation	Capacity
2006	Sun Hung Kai Properties	Ma Wan Theme Park	Small Hydro-turbine	0.5kW
2005	The Chinese University of Hong Kong, Institute of Precision Engineering (IPE)	Upper stream, Wei Yuen Lake	Hydraulic ram pump (non-hydroelectric)	10 L/min
2002	The Chinese University of Hong Kong, Institute of Precision Engineering (IPE)	Wei Yuen (Artificial Lake), Chung Chi College	Wei Yuen Lake Automatic Water Dam	2,600 cubic metres

Return

Renewable Energy:Tidal & Ocean Energy

- Form of hydropower
- Stronger the tide, greater the potential for tidal energy generation
- Two high tides and two low tides around the world at any instant.
- High tide: longitudes closest/furthest from the moon
  Low tide: longitudes 90˚ to the high tide longitudes
- Tidal range: difference in height between high/low tides
  average about 1 m, highest 13 m (Nova Scotia)



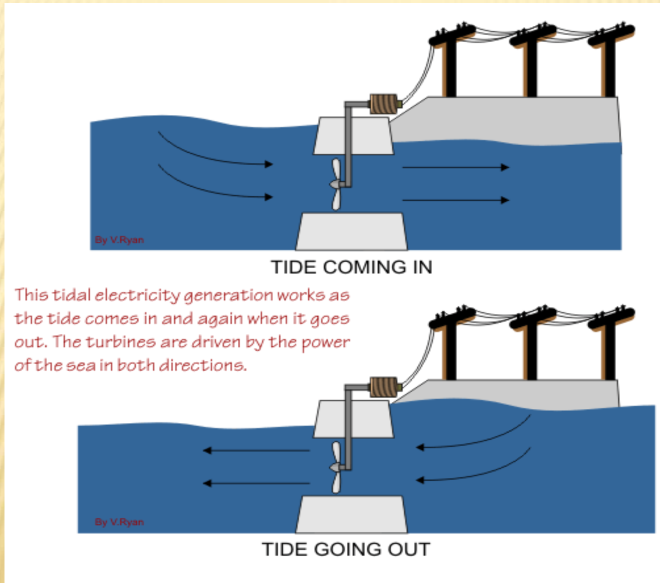
Types of Tidal Power

- use of tidal dams
- use of ocean currents

Use of Tidal Dams

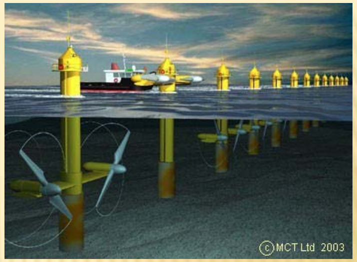
- The turbine is driven by the flow of the tides
- Similar to hydroelectric dam

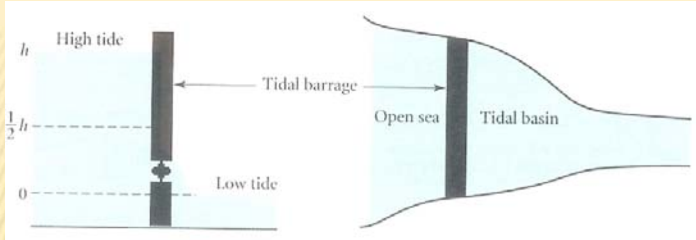
Use of Ocean Currents



Use of Ocean Currents

- Using tidal stream generators, which is similar to wind turbines





❖ Adv. : predictable, carbon-free energy, long plant lives (100 yrs for structure and 40 yrs for equipment), low operating costs.

❖ Disadv.: ecological and environmental impacts (blockage to navigation, fishes killed in turbines, wet/dry habitat is altered, water quality), large capital cost, long construction time.

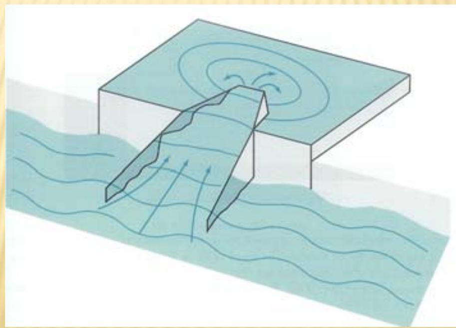
❖ Future: tidal lagoon (the wall does not extend across the whole channel), restrict to shallow water, small tidal current devices (kinetic energy absorbers).

Wave Energy

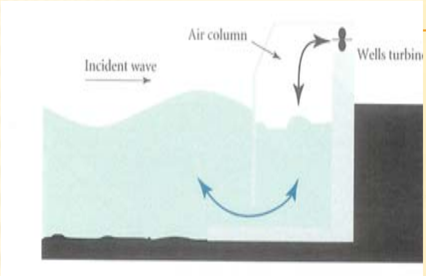
- Waves on the surface of the sea are caused by wind
- 80% of the energy in a surface wave is contained within ¼ of a wavelength below the surface (100 m)
- Power per unit width is proportional to

  $(\text{amplitude})^2 \times (\lambda)^{1/2}$
- Wave power devices: 1st patent in 1799.
- Requirments:
  - survivability in violet storms;
  - Vulnerability of moving parts to sea water;
  - Cost: capital, operational and maintenance
  - Cost of connection to the electricity grid

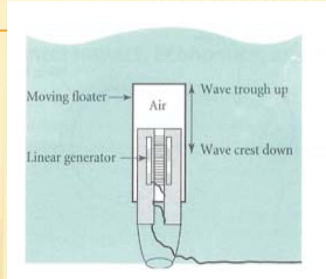
- Types
  - ❖ Spill-over devices: Tapered Channel
    - ❖ Tapering increases the wave amplitude and the wave rises up the ramp, and spills over a reservoir 3-5 m above sea level. Water turbine converts the potential energy into electricity.



- Oscillating water columns (OWC): air turbine housed in a duct wall.

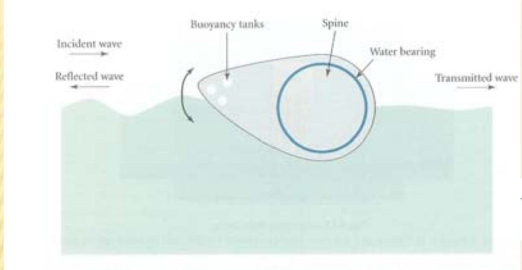


OWC



AWS

- Submerged devices: Archimedes Wave Swing (AWS)
  - point absorber (absorbs power from waves traveling in all directions
  - 50% of the incident power, submerged 6 m below surface
  - simple, no visual impact, avoid damage in violet sea, quick replacement
  - cost effective in term of the power generated per kg of steel



Salter Duck

Pelamis

- Floating devices:

  Salter Duck: rocked back and forth with the incident waves, 90% of the incident power, minimal reflection and transmission, a spinal column used the relative motion between each duck and the spine to provide motive force

  Pelamis: segments rock back and forth, relative motion between segments activates hydraulic rams that pump high pressure oil through hydraulic motors and drive electrical generators

Wave Power

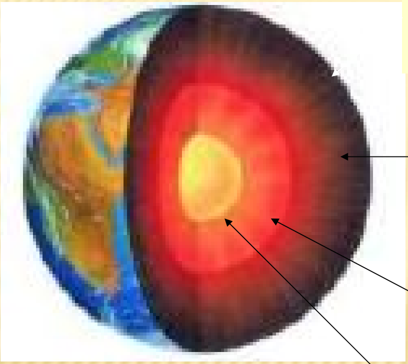
- Advs.: no greenhouse gases
- Disadvs.: visual impact, noise generation, frequency of incident waves is ~ 0.2 Hz (50 - 60 Hz for electricity transmission).
- Potential of wave power ~ 1 – 10 TW
- Main challenges: reduce capital costs, generate electricity at competitive prices, withstand extreme conditions at sea.

Return

Renewable Energy: Geothermal

- The interior temperature of the earth's core is 7000°C.
- The temperature gradient at the earth's surface is 30°C.
- Naturally-occurring steam jets and hot springs up to 350°C.
- Drill boreholes to depth of a few km and flushing water through hot rock.
- <150ºC, used for district heating, industry.
- >150ºC, feed-water heating for electric power plant.
- Two basic types of formation: aquifer (porous rock trapped between layers of impermeable rock), and hot dry rock (radioactive rock).

Earth Structure



Crust

temperature from 15 °C to 500 °C

Mantle

temperature from 700 to 3,000 °C

Outer Core

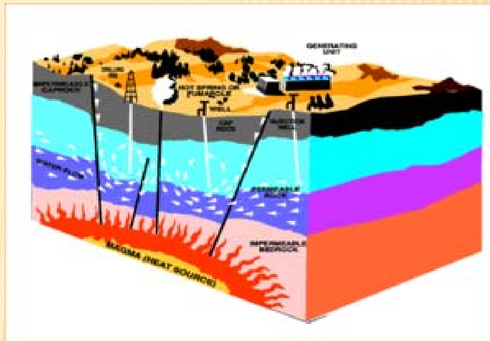
temperature at about 5000 °C

Inner Core

temperature at about 7000 °C

How it works?

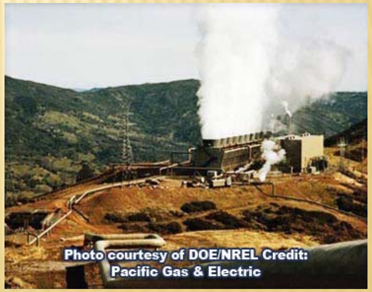
- Geothermal heat that we use is range from shallow ground to hot water and rock several miles below the Earth's surface, and even further down to the extremely hot molten rock called magma.



- Through the movement of underground water and magma, the geothermal heat is transfer to the earth's surface

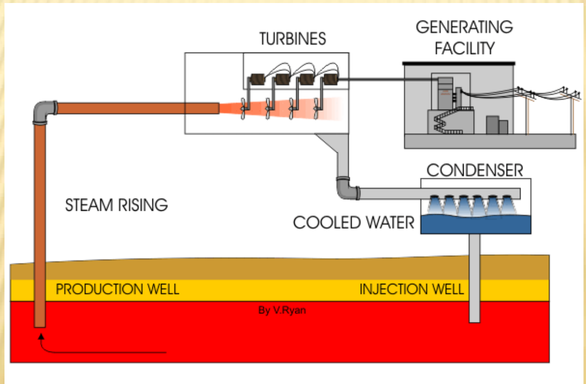
- Wells over a mile deep can be drilled into underground reservoirs to tap steam and very hot water that can be brought to the surface for producing electricity

- There are mainly 3 types of power plants which use geothermal heat to generate electricity
- Dry steam plant
- Flash steam plant
- Binary cycle plant



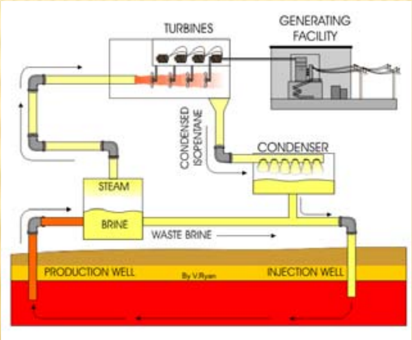
Dry steam plants

- Directly use geothermal steam to turn turbines to generate electricity



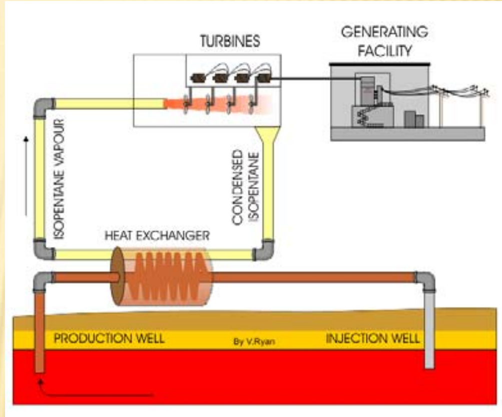
Flash steam plants

- pull deep, high-pressure hot water
- into lower-pressure tanks and use the resulting flashed steam to drive turbines to generate electricity



Binary-cycle plants

- Pass moderately hot geothermal water by a secondary fluid with a much lower boiling point than water. This causes the secondary fluid to flash to vapor, then drives the turbines to generate electricity

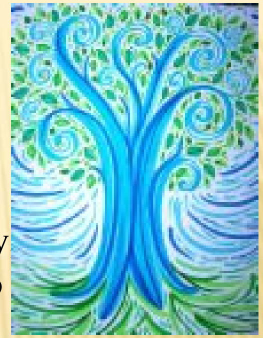


Advantages

- No need to pay for the cost of purchasing fossil fuel, no need to "buy" geothermal heat
- Make use of unlimited natural resources
- Very cost effective
- No combustion of fossil fuel
- No emission of CO_2 and other suspended particulates
- High energy efficiency
- Unaffected by different weather condition
- Environmentally friendly, little environmental impact

Disadvantages

- hot water from geothermal sources will contain trace amounts of dangerous elements such as mercury, arsenic, antimony etc. If the dangerous substances dispose into rivers, it may cause loss of biodiversity (decrease of marine organism population)
- heat exchanger is needed.
- high cost for the boreholes.



Why we still use Geothermal Energy with such Disadvantages?

- Government policy
- A renewable energy law that introduced a tariff scheme of EU €0.15 [US $0.23] per kilowatt-hour (kWh) for electricity produced from geothermal sources was enforced in 2004
- Favor the use of geothermal energy
- No choice in the future, all fossil fuels will be used up
- Advantages > disadvantages

Return

Renewable Energy: Bioenergy

Three main types of bioenergy:

1. Biomass
2. Biogas
3. Biofuels

- Bioenergy is a renewable energy derived from biomass which is organic material such as wood, plants, or animal wastes. Plants derive their energy from Sun: photosynthesis. Animals eat plants.
- Carbon-neutral process:
- $CO_2 + H_2O + h\nu \Longrightarrow O_2 + [CH_2O]$carbohydrate
- Chlorophyll in the plants absorb red and blue ends of solar spectrum. Efficiency (~ 0.5%). Loss due to spread in wavelengths of the solar radiation, losses from leaf (reflection & transmission), short growing period, sustaining the plant etc.
- Produce ~100 TW power in a year. About half, is used in sustaining the plant. In 2002, we use ~ 1.6 TW as energy and ~0.5 TW as food. Biomass supplied ~ 12% of the global energy usage (~ 70% for residential cooking in developing countries).
- Bioenergy can be used to generate electricity, produce heat, and also for the production of biofuels.

Biomass energy production

- Burning/combustion: 95% of biomass energy production. low energy content per Kg, expensive to transport. Poor efficiency (15%). Emissions of CO, particulates. Time spent collecting fuel, deforestation, degradation of soil quality (animal waste), global warming.
- Anaerobic digestion: decomposition of organic matter into methane and CO_2 in the absence of air by bacteria. It is used primarily as a waste management technology. It occurs naturally, such as landfill sites (~ 10 years). In purpose-built digestors with higher temperature (30-60°C), process becomes faster (~ few weeks).
- Municipal solid waste: majority has its origin in photosynthesis – paper(36%), food waste(11%), plant waste(12%), wood(6%).
- Gasification: Burning of biomass in reduced air to form producer gas (CO, H_2, CO_2, CH_4 and N_2). Producer gas has low energy value, but clean with low emission. Producer gas can be further purified into syngas. About 70-85% of energy in biomass transfer into a gaseous form.

- Pyrolysis: chemical decomposition of organic materials by heating in the absence of oxygen. Burning of wood in reduced air to form charcoal. Products include volatile liquids, combustible gases and solid char. Catalysts needed.
- Liquid biofuels: Less petroleum, provides energy security. Low energy content.
- From transesterification of vegetable oils (biodiesel)
- From fermentation of corn or sugar cane (bioethanol)

  $C_6H_{12}O_6 \Longrightarrow 2C_2H_5OH + 2CO_2$

  Small heat released, most of the energy stored in ethanol. Large fossil energy ratio (FER, energy supplied to customer/fossil energy used), if includes energy required on the farm, FER is low.

- Adv.: Sustainable as long as the land quality is maintained, low emission, can be stored easily, energy security.
- Disadv.: Carbon emission (including farming), large area needed.

BioGas

- Biogas is a mixture comprising mainly methane and carbon dioxide. It is produced when organic matter such as vegetables and animal waste decomposes in the absence of oxygen.
- Common biogases such as CH_4, CO_2, H2, CO, N_2, O_2 and H_2S

Anaerobic Digester

An anaerobic digester produces conditions that encourage the natural breakdown of organic matter by bacteria in the absence of oxygen, so that the biomass breaks down much faster than usual.

The digestion process occurs in two stages:

- Acid-forming stage
- Methane-forming stage

anaerobic digester

Biogas Products

Electricity*:* After collecting the biogas from anaerobic digestion process, it is transformed to a specialized generators that generates electricity from biogas.

- **Heat:** As a side product of electricity generation.
- **Fertilizer:** Using the solid and liquid residues from the anaerobic digestion process can also have very beneficial environmental impacts. The amount, quality and nature of these products will depend on the quality of the feedstock, the method of digestion and the extent of the post-treatment refining processes. The main side product of all processes is a solid digestate, which can be matured into product and used as a soil improver or growing media.

Benefits for Production and Our Environment

Benefits from on-farm biogas production:

- ***On-Site Farm Energy***
- ***Reduced Odors***
- ***High Quality Fertilizer***
- ***Reduced Surface and Groundwater Contamination***
- ***Reduction of Pathogen***

Three Most Common Biofuels

- Biodiesel
- Bioethanol
- Biomethanol

BioDiesel

- From vegetable oils
- Replace diesel
- Use in diesel engines likes car
- Feedstocks – agricultural crops such as oilseed rape and sunflower oil

BioAlcohol

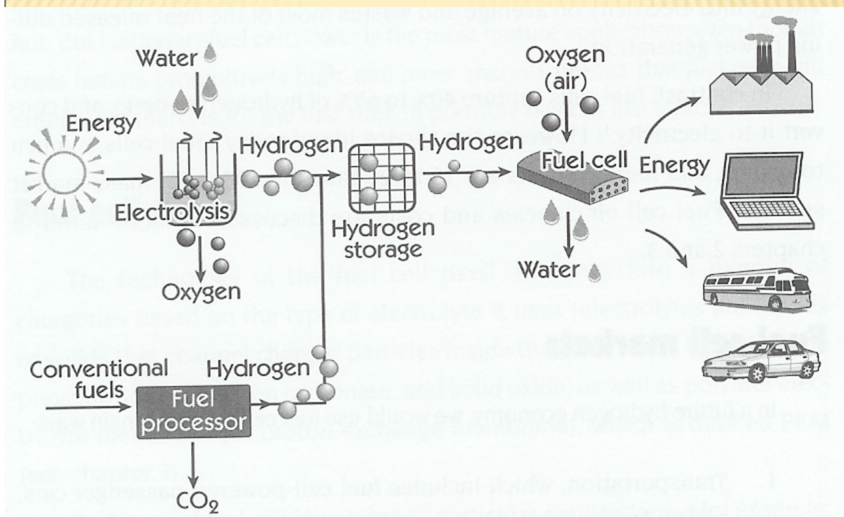
- Most commonly ethanol
- From agricultural feedstock including starch crops(wheat), sugar crops (cane) and woody crops
- Produced by fermentation of sugars
- Used in petrol engines

How Biofuels can be used?

Return

Hydrogen Economy

Hydrogen economy concept: energy storage



Hydrogen

- At room temperature, hydrogen is a gas with two atoms per molecule
- Colourless, odorless, tasteless and nontoxic
- Most abundant element (90%) in the universe
- Not exist by itself, can be produced from water, natural gas, biomass, oil etc.
- Tiny size and lightweight – difficult to store, takes a lot of space
- High energy per unit weight (3x gasoline, 7x coal); low energy per unit volume
- Highly flammable in air, wide range of flammability (4% to 74%)
- Burns with invisible pale-blue flame

- Sustainability, increased energy security, diverse energy supply, reduced air pollution and greenhouse gas emission.
- 95% comes from reforming natural gas, 5% by electrolysis.
- Not an energy source, hydrogen is an energy carrier – a way to transport and store energy
- Decarbonization: Wood (C:H = 10:1), coal (2:1), oil (1:2), natural gas (1:4)

High heating Value

Table II: Higher Heating Values of Various Energy Resources.

Resource	Higher Heating Value (MJ/kg)
Hydrogen	142.0
Natural gas	50.0
Light diesel	46.1
Gasoline	47.3
Ethanol	29.7
Methanol	22.7
Biomass (e.g., wood)	10–20
Coal	14–30

Source: References 11 and 56.
Note: The higher heating value of a fuel is the amount of heat released (MJ) through combustion from 1 kg of fuel source, assuming that the water released in combustion has been condensed to liquid form.

How to generate Hydrogen

- Hydrogen from Biomass
  - Agricultural and forest residues, consumer wastes, special crops composed of cellulose, hemicellulose and lignin
  - Thermochemical processes of gasification and pyrolysis
  - Gasification: vapourize the biomass at 600ºC

    biomass + O_2 ⟹ $CO + H_2 + CO_2$ + char

    gasify the char at 800ºC : $CO + H_2O$ ⟹ $CO_2 + H_2$
  - Pyrolysis: thermally degrades biomass in the absence of oxygen into bio-oil at 500 to 800ºC

    biomass + energy ⟹ gases + char + bio-oil

    The bio-oil/gases are converted into hydrogen using catalytic steam at 800ºC

    bio-oil/gases + H_2O ⟹ $CO_2 + H_2$
  - Adv: abundant source, other useful by-product
  - Disadv: needs high temperature, CO_2 formed, handles a range of low-cost feedstocks, special catalyst needed

- Hydrogen from electrolysis
  - Use low cost renewable energies to generate electricity to run electrolyzer

    $2H_2O$ + electricity ⟹ $2H_2 + O_2$
  - Due to the advances in wind turbines, low cost wind power (~3 to 7 ¢/kWh) is the most commonly used renewable energy.
  - Proton exchange membrane (PEM) electrolyzer: polymeric membrane sandwiched between two catalyst-coated electrodes.
  - Power electronics needed to convert AC to DC.
  - Hydrogen used as a storage for convenience usage of renewable energy.

•Direct Hydrogen Production (water-splitting/water-cracking)

- Use direct sunlight to dissociate water into hydrogen and oxygen
- Ultimate clean and sustainable hydrogen production method
- 1st method : **Photoelectrochemical (PEC) devices**
- PEC integrates photovoltaic materials with electrolyzer, eliminates costs, increases efficiency by 30%
- Challenge: materials – correct energies to drive the electrolysis and stable
- GaN, amorphous Si, copper indium gallium diselenide (CIGS)
- 2nd method : **Photosynthetic microorganisms (photobiological)**
- Green alga uses sunlight to produce hydrogen and oxygen from water
- Oxygen inhibits the function of enzyme that catalyzes the release of hydrogen (normal condition: not longer than few minutes)
- New forms of organisms that can sustain hydrogen production in the presence of oxygen or develop processes that separate the oxygen and hydrogen.

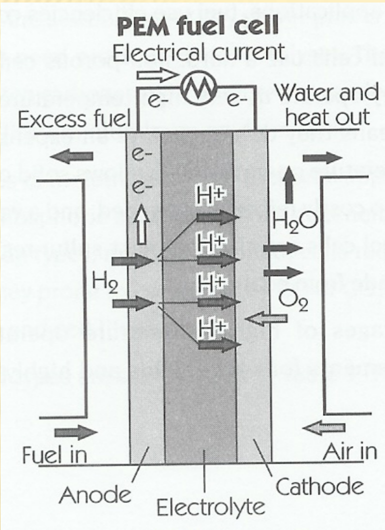
•Hydrogen Storage

- Develop a safe, reliable, cost-effective way to store hydrogen
- Hydrogen is lightweight. If it leaked, disperse upward, can't spill into the ground and contaminate the water supply
- Highly flammable – burn in low conc (4%)
- No smell, burn with invisible pale-blue flame, hard to see.
- Present technologies: compressed gas at high pressure and liquid hydrogen (-253ºC)
- Future technologies: metal hydrides, carbon nanotubes based on physisorption or chemisorption.

•Problems

- Better process needed: making hydrogen from water/natural gas consumes more energy than we get – onsite hydrogen production eliminates the energy for transportation
- High cost of delivering: 5 times higher than production
- High cost of electrolyzers/fuel cells

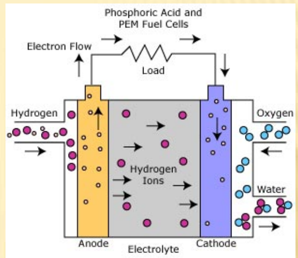
Fuel Cells



•Capture 65 % of hydrogen's energy and convert it to electricity.

•Power Station converts 35% of fuel energy into electricity.

•Generate power more efficiently than car engine running on gasoline (2.5 x)



•Modular design – easily up-scaled, flexibility

•No movable parts – no maintenance

•Types: type of electrolyte used

- Phosphoric acid: 1st type, most mature, used commercially, large
- Molten carbonate: 650ºC, high efficiency (60%), short life-time
- Alkaline: KOH in water, 200ºC, easily poisoned, space craft
- Solid oxide: 1000ºC, highest efficiency (85%)
- Polymer electrolyte membrane (proton exchange membrane) (100ºC)

Fuel Cell Technologies Summary

Fuel cell type	Temp. range	Efficiency*	Electrolyte	Capacities	Primary application	Notes
Polymer electrolyte or proton exchange membrane	<100°C (<212°F)	50–60%	Polymer membrane (thin plastic film)	100 W to 250 kW per cell	Transportation, stationary	Fast startup, high power density, rapid response to power demand, relatively rugged
Phosphoric acid	160°–220°C (320–430°F)	37–55%; up to 72–80% with heat recovery	Concentrated phosphoric acid	25–250 kW per cell	Stationary	Fuel of choice is natural gas
Solid oxide	800°–1,000°C (1,500–1,800°F)	45–65%; up to 70–85% with heat recovery	Solid nonporous ceramic materials	200 W per cell; 300 kW to 3 MW per module	Stationary, utility	Typically applied in stacks of hundreds; a plant might produce up to 10 MW
Alkaline	23°–250°C (70–482°F)	50–60%	Potassium hydroxide solution (35–50% KOH)	2.2 kW	Spacecraft	Being developed for other applications
Molten carbonate	650°–660°C (1,200°F)	45–60%; 70–85% with heat recovery	Melted carbonate salt mixture	250 kW to >1 MW	Stationary, utility	Corrosive electrolyte limits durability

- Applications
  - Transportation: cars, ships and planes
  - Stationary: home units to multi-megawatt power stations
  - Portable electronic appliances: cell-phones, computers
- Problems
  - High cost
  - Short life-time

Why are the Renewable Energies Still Not Common among Nations?

1. Low Efficiency
2. Location-Restraints
3. Technological Insufficient
4. High Construction and Maintenance Costs
5. Disturbances of natural environment

Low Efficiency of Renewable Energy

→*Renewable sources are far less efficient : fewer energy resources are converted into electricity*

-e.g. wind power-25%, solar panels-10 %, geothermal power-8 % and biomass power-1 %

-compared to non-renewable energy :gas-fired power - 38 to 58%, coal-fired – 45%,nuclear power -33 %

→*Low power density:*

-defined ratio of installed capacity (in MW) or energy production (in GWh) to the area (in m^2) occupied by the power plant.

- By the definition, power density increases with higher installed capacity or energy output and with lower area occupied by the power plant

VOLATILITY AND UNPREDICTABILITY OF

→Due to natural changes in wind intensity or solar radiation, renewable energy sources generally operate fewer hours at full capacity.

E.g., thermal power plants can operate for 7000-7500 hrs annually (1 year has 8760 hrs) and wind power plants operate for 2000-3000 hours annually.

→ Does not mean that the power plant operates for more hours, the power plant would operates necessarily at installed (full) capacity

→not possible to predict with complete certainty the intensity of a wind or solar radiation in the short term

→volatile nature of renewable energy sources limits the possibilities of their feeding the grid. Electricity production from renewable energy sources varies greatly during the day making it hard to plan when the power plant will be in operation

Location Restraints

→Many Renewable energies are limited in certain locations:

e.g., HEP, Tidal Power, Wind Power, Solar Power

→Volatile nature of renewable energy sources limits the possibilities of their feeding the grid

→Difficult to be transported in long distance: areas far away from the resource sites may not be benefited from the renewable energy

→Non-renewable energy, e.g. Crude oil and natural gas do not have this problem : can be easily transported by ships or pipes

Technological Insufficient

→In LDCs: do not know how to make use of the renewable power resources: no R&D in this areas, also no knowledge in the operation of the power plants

e.g. the making of the solar panels

→Energy used are still mainly non-renewable resources

→Inefficiency in generating power resources in electricity: low efficiency of renewable energy

High Construction and maintenance Costs Technologies Summary

→High Construction Costs: the construction of the power plants, specialized equipments and land price of the large areas occupied

→cost of the raw material (fuel) used to generate electricity nor the cost of operation and maintenance of the plant, which are very important in arriving at the cost of a plant's electricity production.

→The production cost includes all of these factors as well as the construction cost (e.g. HRK/kWh).

→For renewable energy, a source may be free of cost, but the high construction cost and the low number of annual operating hours cause high electricity prices

× *Disturbances of natural Environment*

-During time of construction and production →pollutants produced
e.g. the production of solar panels produced many greenhouses gases then it can prevent in the generation of energy

-For those location limited renewable energy: relocation of housings and people are needed

-Natural scenery and views maybe destroyed

e.g. The Three gorges projects in ChangJiang submerged the upper course of ChangJiang and many old towns were being inundated, also the wildlife habitat of the marine life had been badly disturbed, moreover, the natural appearance of the lower course is being modified by the dam built

Conclusion

- Energy problem:
  - Solution: not just renewable energy, look at the problem including source, usage, storage and transportation etc.
  - Growth rate of renewable energy cannot catch up the increase in energy usage. For example, large growth rate in wind & PV (27% & 40%); 15% growth rates – 20 years to provide 20% overall electricity
  - development of energy technologies from source to use
  - supply side – energy generation, distribution
  - demand side – efficiency in delivery and consumption
  - smart usage:
    - buildings construction (passive heating, sensors, PV cells)
    - LED lighting (light bulbs 5%, florescence lamps 15%, LED 30%)
    - automobiles (hybrid engine, fuel cell car, light weight steels)

Renewable Energy in Hong Kong

• Hydrothermal power, traditional biomass, ocean energy and geothermal are not feasible in Hong Kong.

• Solar energy:

•Solar heater system: provides hot water

1978 Hotel complex in TsimShaTsui
1983 Hei Ling Chau drug addiction treatment center and Shek Pik prison
1994 hydrotherapy pool in Tuen Mun Hospital
1998 Shing Mun Valley swimming pool complex
1999 Sheung Shui slaughterhouse

•Marine Department: 90% of lighted buoys and beacons

•Building Integraed Photovoltaic system in Wan Chai Tower (2003), Science Park building and primary school in Ma Wan.

•Hong Kong observatory; solar cell to power automatic weather stations

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