# ENERGY MANAGEMENT (BME-56)

**Unit-I**

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# Sources of Energy

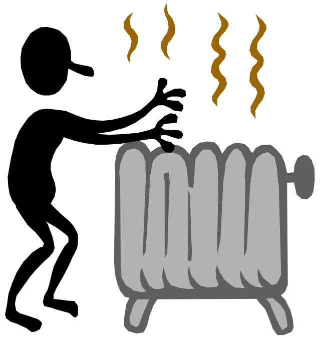
Renewable and Non-renewable

# What is Energy?

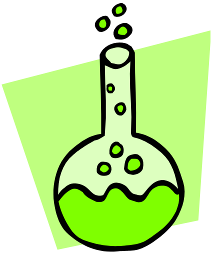
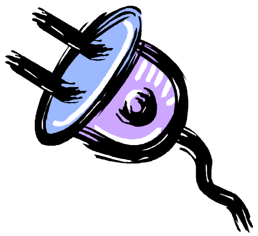
- Energy is the ability to do work

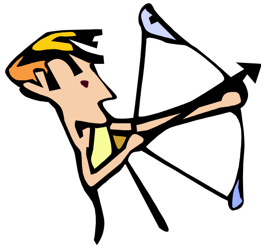
# Energy Forms

- Heat
- Light
- Sound
- Kinetic (movement)
- Chemical
- Electrical
- Gravitational
- Elastic (potential)







# Sources of Energy

All forms of energy are stored in different ways, in the energy sources we use every day.  These sources are divided into 2 groups.

# Sources of Energy

- Renewable

An energy source that can be replenished in a short period of time.

- Non – Renewable

An energy source that we cannot replace.

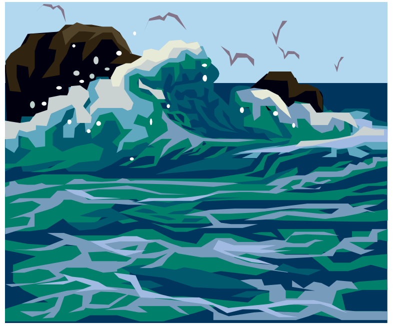
# Renewable Energy

- Sun

  - Wind

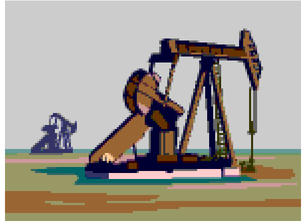
  - Geothermal

  - Biomass (plants)
  - Water



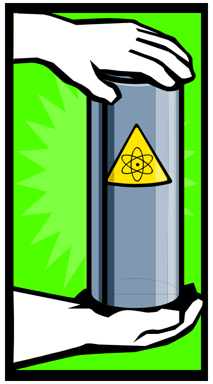
# Non-Renewable Energy

- Oil



- Coal

- Natural Gas
- Nuclear



# ENERGY FORMS AND CHANGES

# Nature of Energy

- Energy is all around you!
  - You can hear energy as sound.
  - You can see energy as light.
  - And you can feel it as wind.

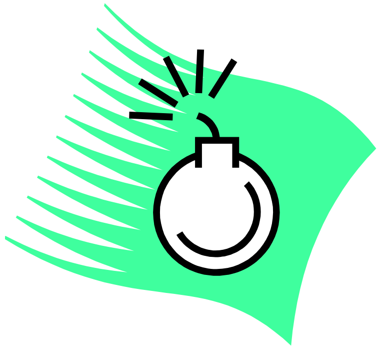
# Nature of Energy

- You use energy when you:
  - hit a softball.
  - lift your book bag.
  - compress a spring.

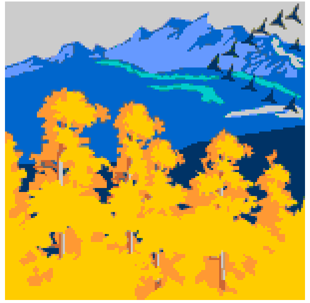
# Nature of Energy

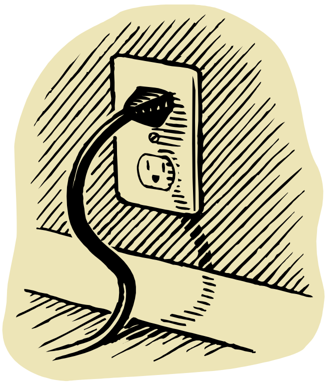
Living organisms need energy for growth and movement.

# Nature of Energy



- Energy is involved when:
  - a bird flies.
  - a bomb explodes.
  - rain falls from the sky.
  - electricity flows in a wire.





# Nature of Energy

- What is energy that it can be involved in so many different activities?
  - Energy can be defined as the ability to do work.
  - If an object or organism does work (exerts a force over a distance to move an object) the object or organism uses energy.

# Nature of Energy

- Because of the direct connection between energy and work, energy is measured in the same unit as work: joules (J).
- In addition to using energy to do work, objects gain energy because work is being done on them.

# Forms of Energy

- The five main forms of energy are:
  - Heat
  - Chemical
  - Electromagnetic
  - Nuclear
  - Mechanical

# Heat Energy

- The internal motion of the atoms is called heat energy, because moving particles produce heat.
- Heat energy can be produced by friction.
- Heat energy causes changes in temperature and phase of any form of matter.

# Chemical Energy

- Chemical Energy is required to bond atoms together.
- And when bonds are broken, energy is released.

# Chemical Energy

- Fuel and food are forms of stored chemical energy.

# Electromagnetic Energy

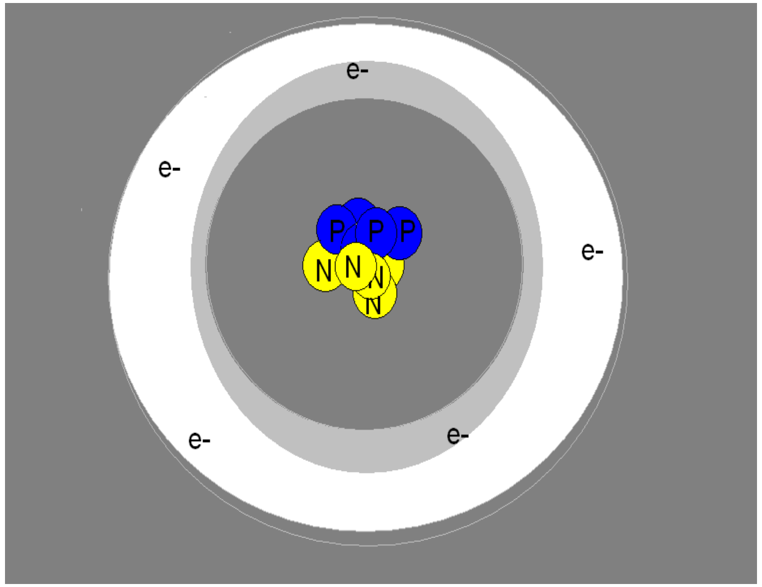
- Power lines carry electromagnetic energy into your home in the form of electricity.

# Electromagnetic Energy

- Light is a form of electromagnetic energy.
- Each color of light (Roy G Bv) represents a different amount of electromagnetic energy.
- Electromagnetic Energy is also carried by X-rays, radio waves, and laser light.

# Nuclear Energy

- The nucleus of an atom is the source of nuclear energy.



# Nuclear Energy

- When the nucleus splits (fission), nuclear energy is released in the form of heat energy and light energy.
- Nuclear energy is also released when nuclei collide at high speeds and join (fuse).

# Nuclear Energy

The sun’s energy is produced from a nuclear fusion reaction in which hydrogen nuclei fuse to form helium nuclei.

# Nuclear Energy

- Nuclear energy is the most concentrated form of energy.

Most of us live within 10 miles of the Surry Nuclear Power Plant which converts nuclear energy into electromagnetic energy.

# Mechanical Energy

- When work is done to an object, it acquires energy. The energy it acquires is known as mechanical energy.

# Mechanical Energy

- When you kick a football, you give mechancal energy to the football to make it move.

# Mechanical Energy

**When you throw a balling ball, you give it energy. When that bowling ball hits the pins, some of the energy is transferred to the pins (transfer of momentum).**

# Energy Conversion

- Energy can be changed from one form to another. Changes in the form of energy are called energy conversions.

# Energy conversions

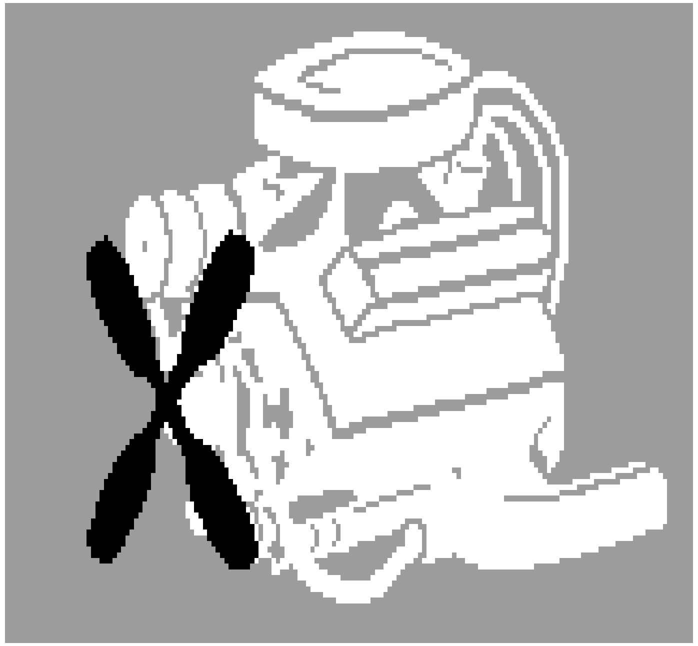
- All forms of energy can be converted into other forms.
  - The sun's energy through solar cells can be converted directly into electricity.
  - Green plants convert the sun's energy (electromagnetic) into starches and sugars (chemical energy).

# Other energy conversions

- In an electric motor, electromagnetic energy is converted to mechanical energy.
- In a battery, chemical energy is converted into electromagnetic energy.
- The mechanical energy of a waterfall is converted to electrical energy in a generator.

# Energy Conversions

- In an automobile engine, fuel is burned to convert chemical energy into heat energy. The heat energy is then changed into mechanical energy.



Chemical → Heat →Mechanical

# States of Energy

- The most common energy conversion is the conversion between potential and kinetic energy.
- All forms of energy can be in either of two states:
  - Potential
  - Kinetic

# States of Energy:
# Kinetic and Potential Energy

- Kinetic Energy is the energy of motion.
- Potential Energy is stored energy.

# Kinetic Energy

- The energy of motion is called kinetic energy.
- The faster an object moves, the more kinetic energy it has.
- The greater the mass of a moving object, the more kinetic energy it has.
- Kinetic energy depends on both mass and velocity.

# Kinetic Energy

$$K.E. = \frac{\text{mass x velocity2}}{2}$$

What has a greater affect of kinetic energy, mass or velocity? Why?

# Potential Energy

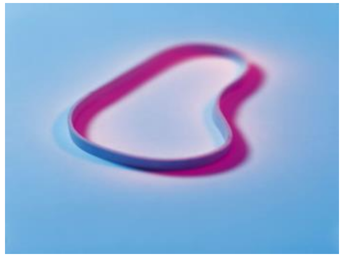
- Potential Energy is stored energy.
  - Stored chemically in fuel, the nucleus of atom, and in foods.
  - Or stored because of the work done on it:
    - Stretching a rubber band.
    - Winding a watch.
    - Pulling back on a bow’s arrow.
    - Lifting a brick high in the air.

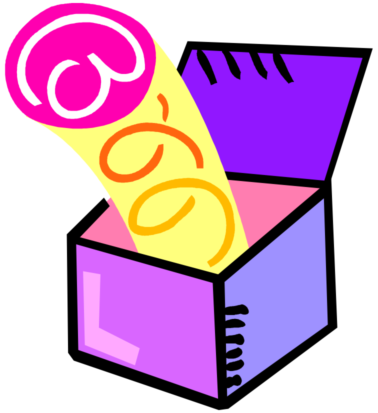
# Gravitational Potential Energy

- Potential energy that is dependent on height is called gravitational potential energy.

# Potential Energy

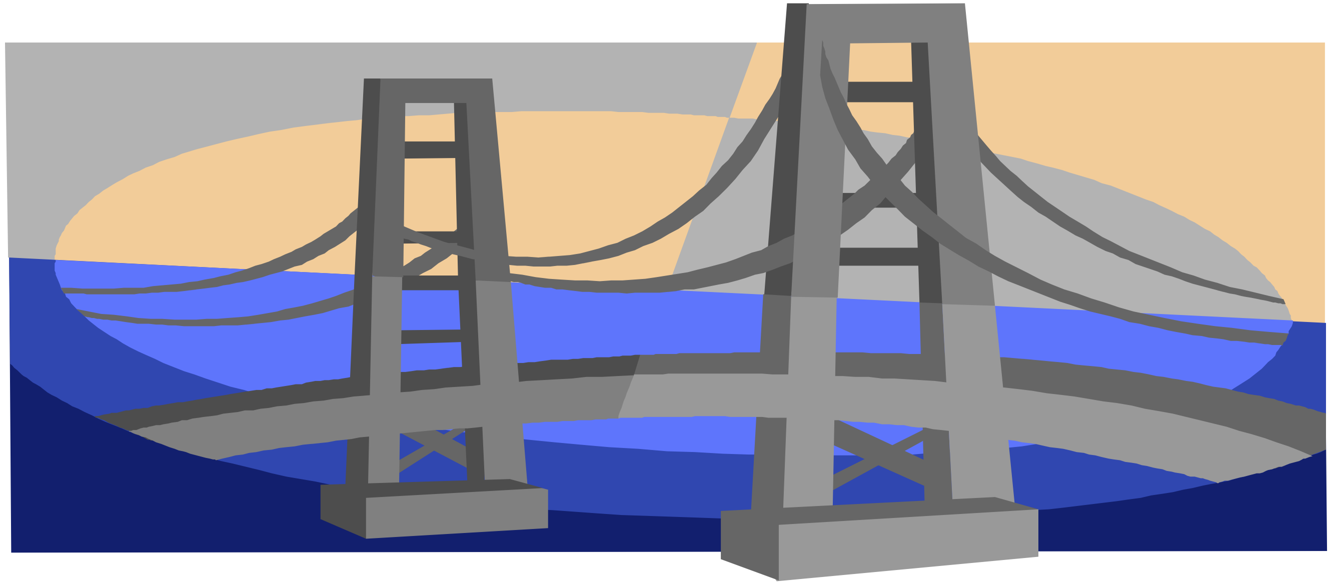
- Energy that is stored due to being stretched or compressed is called elastic potential energy.





# Gravitational Potential Energy

- A waterfall, a suspension bridge, and a falling snowflake all have gravitational potential energy.



# Gravitational Potential Energy

- If you stand on a 3-meter diving board, you have 3 times the G.P.E, than you had on a 1-meter diving board.

# Gravitational Potential Energy

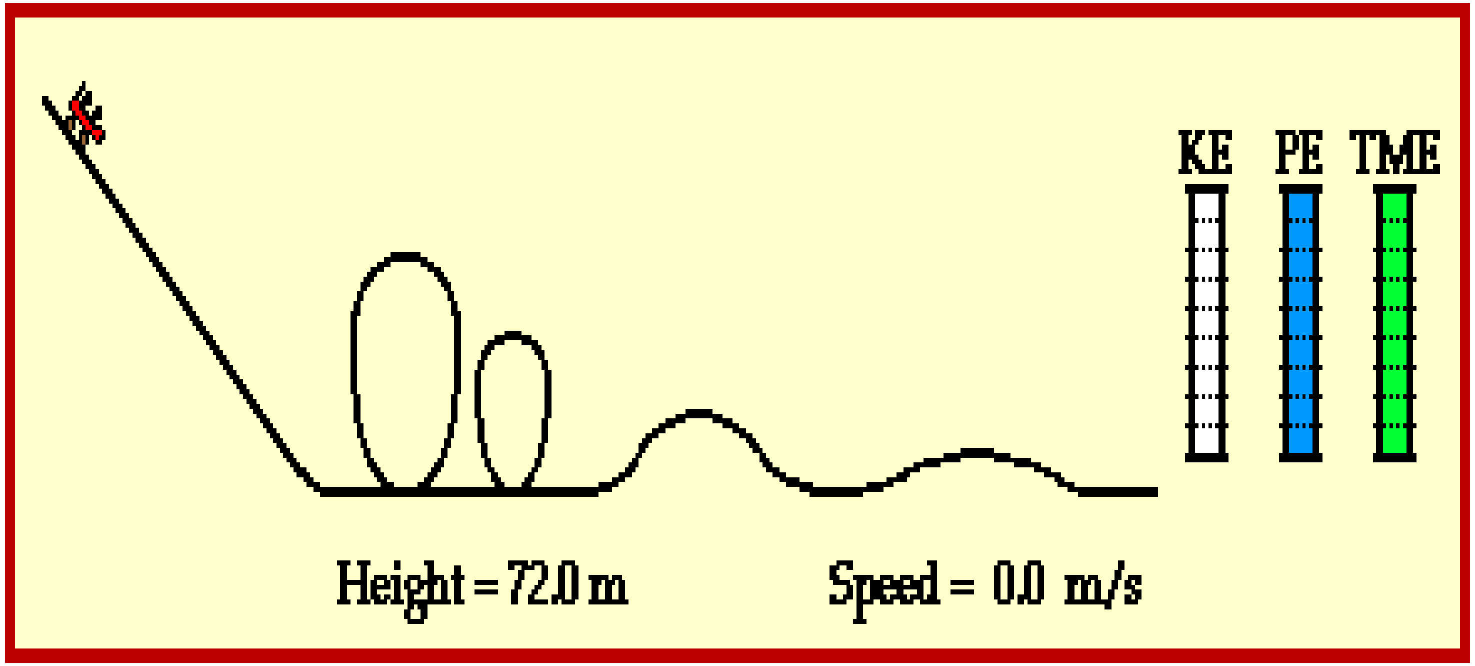
- "The bigger they are the harder they fall" is not just a saying. It's true. Objects with more mass have greater G.P.E.
- The formula to find G.P.E. is

  G.P.E. = Weight X Height.

# Kinetic-Potential Energy Conversion

Roller coasters work because of the energy that is built into the system. Initially, the cars are pulled mechanically up the tallest hill, giving them a great deal of potential energy. From that point, the conversion between potential and kinetic energy powers the cars throughout the entire ride.

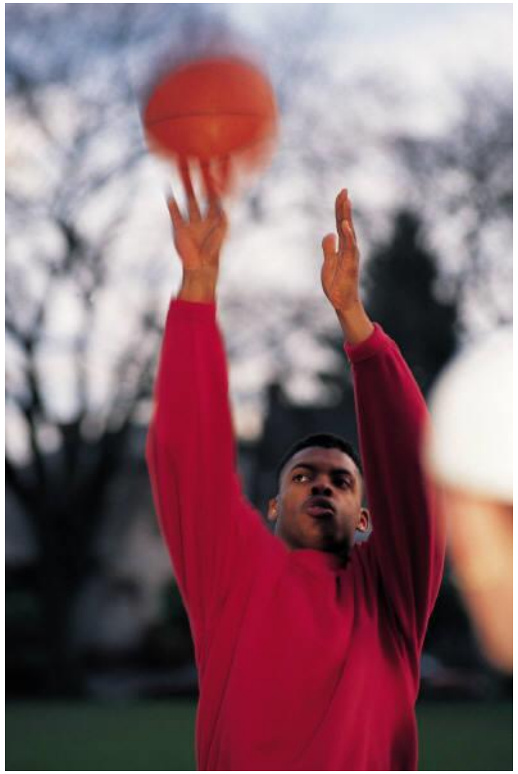
# Kinetic vs. Potential Energy

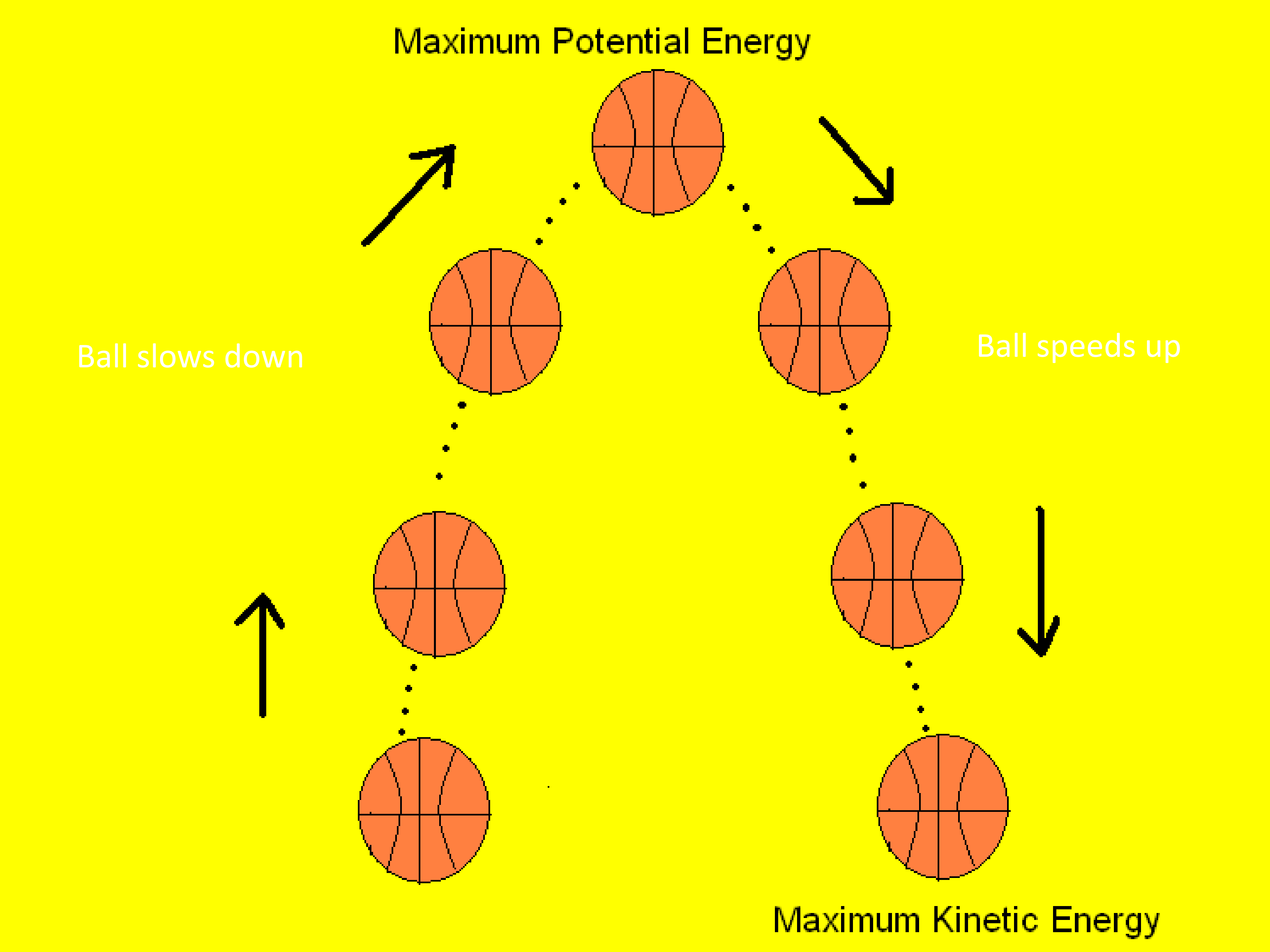



At the point of maximum potential energy, the car has minimum kinetic energy.

# Kinetic-Potential Energy Conversions

- As a basketball player throws the ball into the air, various energy conversions take place.




Maximum Potential Energy
Ball slows down
Ball speeds up
Maximum Kinetic Energy

# The Law of Conservation of Energy

- Energy can be neither created nor destroyed by ordinary means.
  - It can only be converted from one form to another.
  - If energy seems to disappear, then scientists look for it – leading to many important discoveries.

# Law of Conservation of Energy

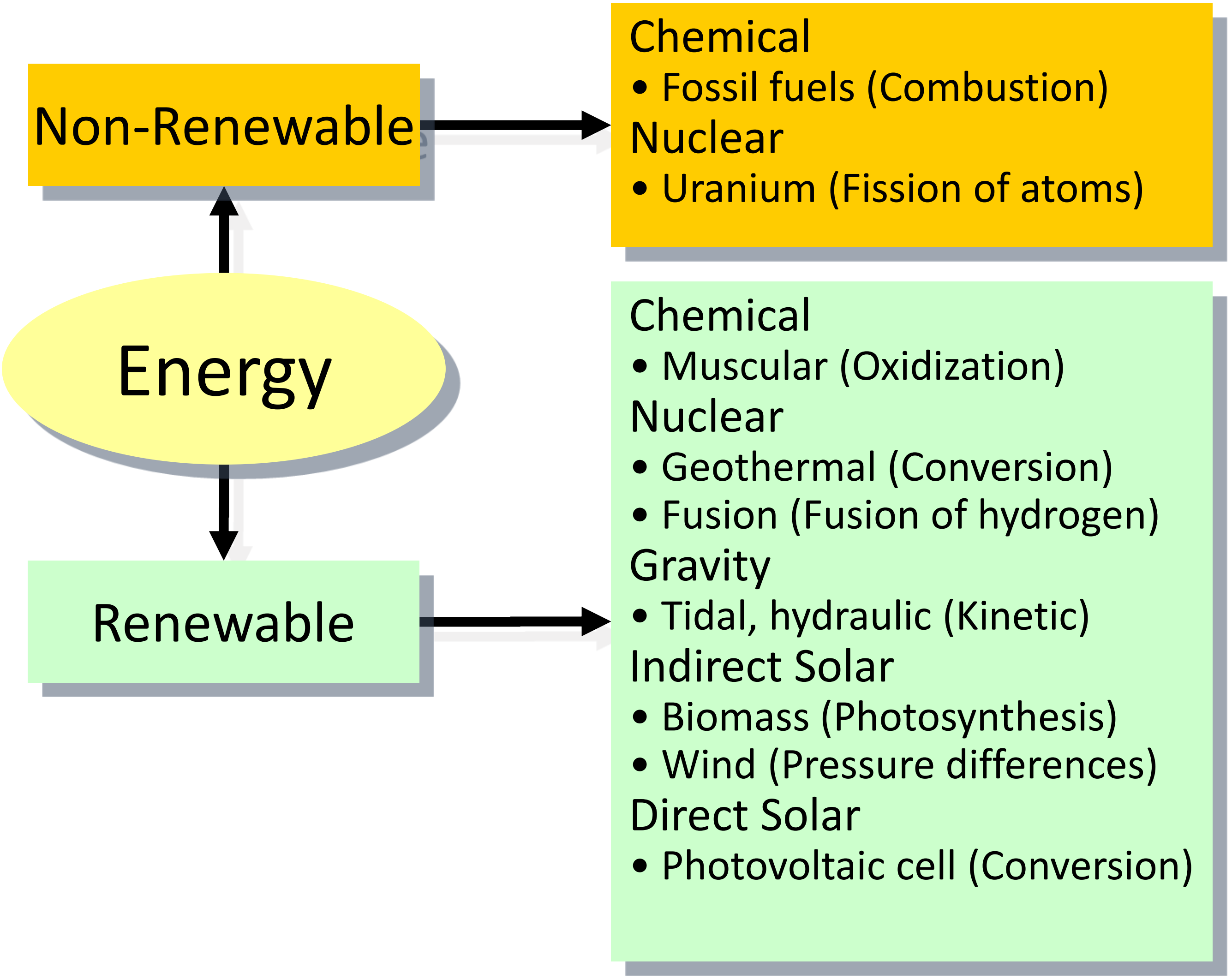
- In 1905, Albert Einstein said that mass and energy can be converted into each other.
- He showed that if matter is destroyed, energy is created, and if energy is destroyed mass is created.
    - E = MC2

# SOURCES AND USE

# Sources of Energy

- Nature
    - Energy is movement or the possibility of creating movement:
        - Exists as potential (stored) and kinetic (used) forms.
    - Conversion of potential to kinetic.
    - Movement states:
        - Ordered (mechanical energy) or disordered (thermal energy).
        - Temperature can be perceived as a level of disordered energy.
        - Major tendency is to move from order to disorder (entropy).
- Importance
    - Human activities are dependant on the usage of several forms and sources of energy.
    - Energy demands:
        - Increased with economic development.
        - The world's power consumption is about 12 trillion watts a year, with 85% of it from fossil fuels.

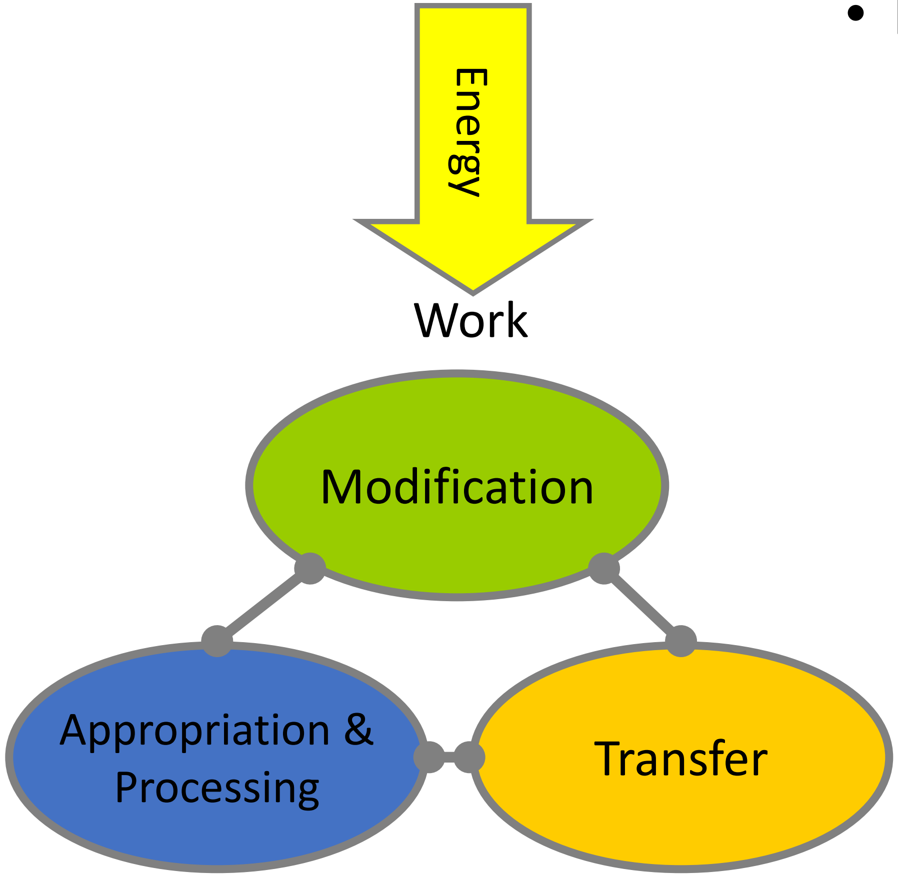
# Sources of Energy



# Sources of Energy

- Energy transition
  - Shift in the sources of energy that satisfy the needs of an economy / society.
  - Linked with economic and technological development.
  - Linked with availability and/or remaining energy sources.
  - From low efficiency to high efficiency.
  - From solids, to liquids and then gazes:
    - Wood, Coal.
    - Oil.
    - Natural gas and hydrogen.

# Energy Use




- Energy and work
  - Energy provides work.
  - Technology enables to use energy more efficiently and for more purposes.
  - Traditionally, most of the work was performed by people:
    - Many efforts have been done to alleviate work.
  - Creating more work performed by machines and the usage of even more energy.

# Energy Use

| Modification of the Environment | Appropriation and Processing | Transfer |
| --- | --- | --- |
| ■ Making space suitable for human activities.<br>■ Clearing land for agriculture.<br>■ Modifying the hydrography (irrigation).<br>■ Establishing distribution infrastructures (roads).<br>■ Constructing and conditioning (temperature and light) enclosed structures. | ■ Extraction of resources (agricultural products and raw materials).<br>■ Modifying resources (manufacturing).<br>■ Disposal of wastes (Piling, decontaminating and burning). | ■ Movements of freight, people and information.<br>■ Attenuate the spatial inequities in the location of resources by overcoming distance.<br>■ Growing share of transportation in the total energy spent |

# Challenges

- Energy Supply
  - Providing supply to sustain growth and requirements.
  - A modern society depends on a stable and continuous flow of energy.
- Energy Demand
  - Generate more efficient devices:
    - Transportation.
    - Industrial processes.
    - Appliances.
- Environment
  - Provide environmentally safe sources of energy.
  - Going through the energy transition (from solid to gazes).

# Conventional Energy Resources

- What sources of energy have filled our requirements so far?
- 1. Coal
- 2. Petroleum
- 3. Natural Gas
- 4. Hydropower
- 5. Nuclear Power

# Coal

- Nature
  - Formed from decayed swamp plant matter that cannot decompose in the low-oxygen underwater environment.
  - Coal was the major fuel of the early Industrial Revolution.
  - High correlation between the location of coal resources and early industrial centers:
    - The Midlands of Britain.
    - Parts of Wales.
    - Pennsylvania.
    - Silesia (Poland).
    - German Ruhr Valley.
  - Three grades of coal.

# Coal

- Coal use
  - Thermal coal (about 90% use):
    - Used mainly in power stations to produce high pressure steam, which then drives turbines to generate electricity.
    - Also used to fire cement and lime kilns.
    - Until the middle of the 20th Century used in steam engines.
  - Metallurgical coal:
    - Used as a source of carbon, for converting a metal ore to metal.
    - Removing the oxygen in the ore by forcing it to combine with the carbon in the coal to form CO2.
  - Coking coal:
    - Specific type of metallurgical coal.
    - Used for making iron in blast furnaces.
  - New redevelopment of the coal industry:
    - In view of rising energy prices.

# Petroleum

- Nature
  - Formation of oil deposits:
    - Decay under pressure of billions of microscopic plants in sedimentary rocks.
    - “Oil window”;  7,000 to 15,000 feet.
    - Created over the last 600 million years.
  - Exploration of new sources of petroleum:
    - Related to the geologic history of an area.
    - Located in sedimentary basins.
    - About 90% of all petroleum resources have been discovered.
  - Production vs. consumption:
    - Geographical differences.
    - Contributed to the political problems linked with oil supply.

# Petroleum

- Use
  - Transportation:
    - The share of transportation has increased in the total oil consumption.
    - Accounts for more the 55% of the oil used.
    - In the US, this share is 70%.
    - Limited possibility at substitution.
  - Other uses (30%):
    - Lubricant.
    - Plastics.
    - Fertilizers.
  - Choice of an energy source:
    - Depend on a number of utility factors.
    - Favoring the usage of fossil fuels, notably petroleum.

# Natural Gas

- Nature
  - Formation:
    - Thermogenic: converted organic material into natural gas due to high pressure.
    - Deeper window than oil.
    - Biogenic: transformation by microorganisms.
  - Composition:
    - Composed primarily of methane and other light hydrocarbons.
    - Mixture of 50 to 90% by volume of methane, propane and butane.
    - “Dry” and “wet” (methane content); “sweet” and “sour” (sulfur content).
  - Usually found in association with oil:
    - Formation of oil is likely to have natural gas as a by-product.
    - Often a layer over the petroleum.

# Natural Gas

- Reserves
  - Substantial reserves likely to satisfy energy needs for the next 100 years.
  - High level of concentration:
    - 45% of the world’s reserves are in Russia and Iran.
  - Regional concentration of gas resources is more diverse:
    - As opposed to oil.
    - Only 36% of the reserves are in the Middle East.

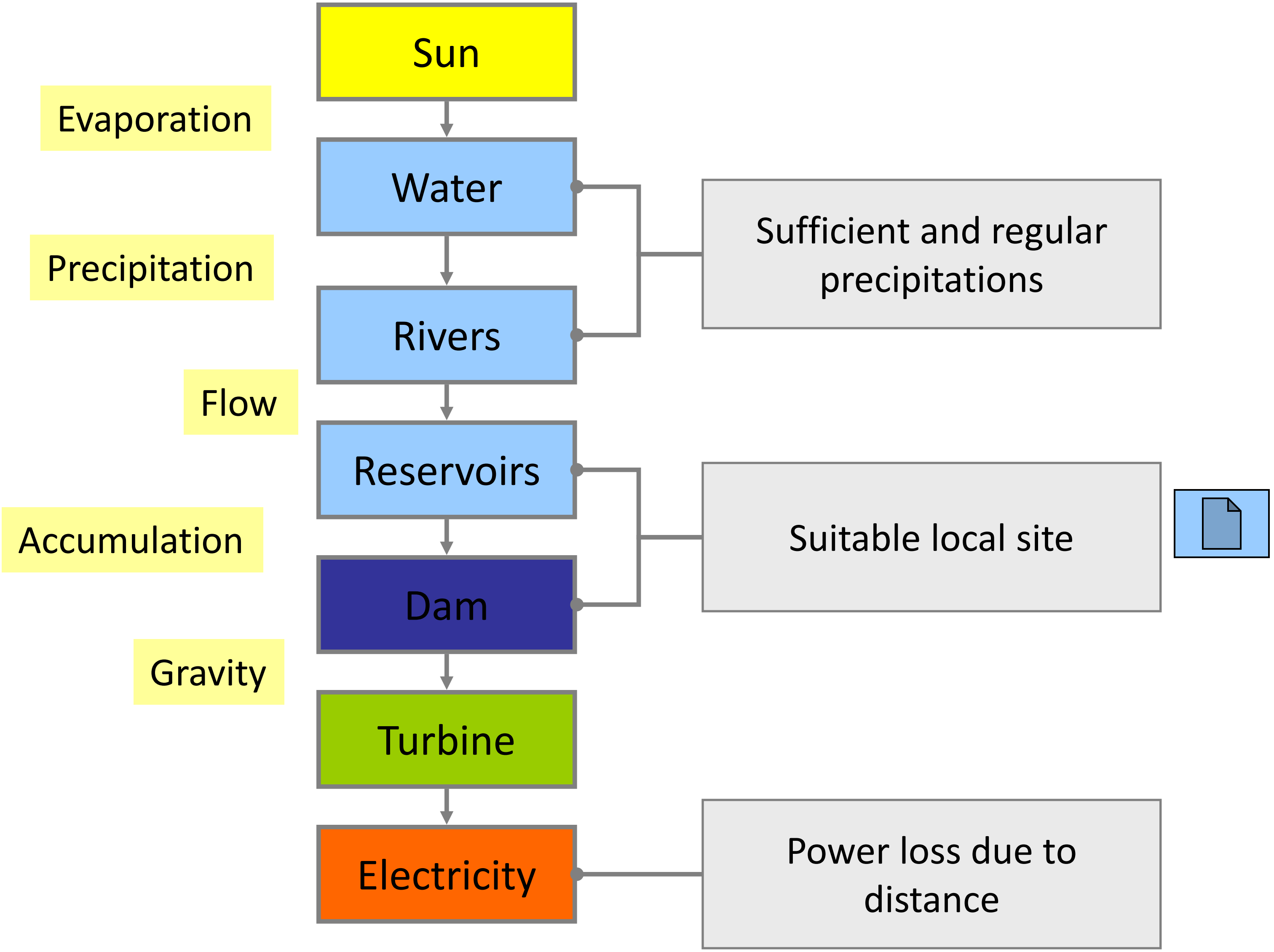
# Natural Gas

- Use
  - Mostly used for energy generation.
  - Previously, it was often wasted - burned off.
  - It is now more frequently conserved and used.
  - Considered the cleanest fossil fuel to use.
  - The major problem is transporting natural gas, which requires pipelines.
  - Gas turbine technology enables to use natural gas to produce electricity more cheaply than using coal.

# Hydropower

- Nature
  - Generation of electricity using the flow of water as the energy source.
  - Gravity as source.
  - Requires a large reservoir of water.
  - Considered cleaner, less polluting than fossil fuels.
- Tidal power
  - Take advantage of the variations between high and low tides.

# Hydropower


Sun
Evaporation
Water
Precipitation
Rivers
Flow
Reservoirs
Accumulation
Dam
Gravity
Turbine
Electricity
Sufficient and regular precipitations
Suitable local site
Power loss due to distance

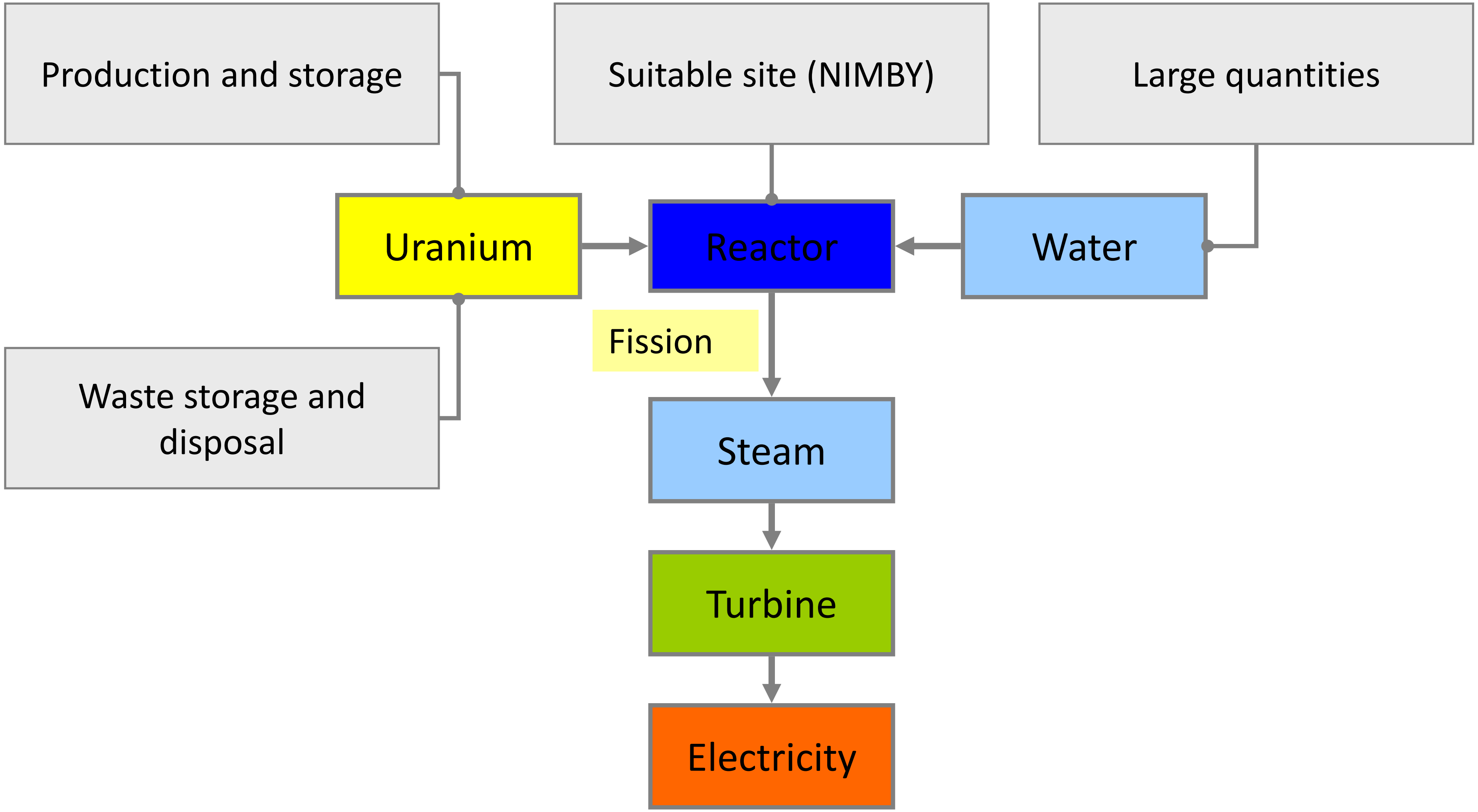
# Hydropower

- Controversy
  - Require the development of vast amounts of infrastructures:
    - Dams.
    - Reservoirs.
    - Power plants and power lines.
    - Very expensive and consume financial resources or aid resources that could be utilized for other things.
  - Environmental problems:
    - The dams themselves often alter the environment in the areas where they are located.
    - Changing the nature of rivers, creating lakes that fill former valleys and canyons, etc.

# Nuclear Power

- Nature
  - Fission of uranium to produce energy.
  - The fission of 1 kg (2.2 lb) of uranium-235 releases 18.7 million kilowatt-hours as heat.
  - Heat is used to boil water and activate steam turbines.
  - Uranium is fairly abundant.
  - Requires massive amounts of water for cooling the reactor.

# Nuclear Power



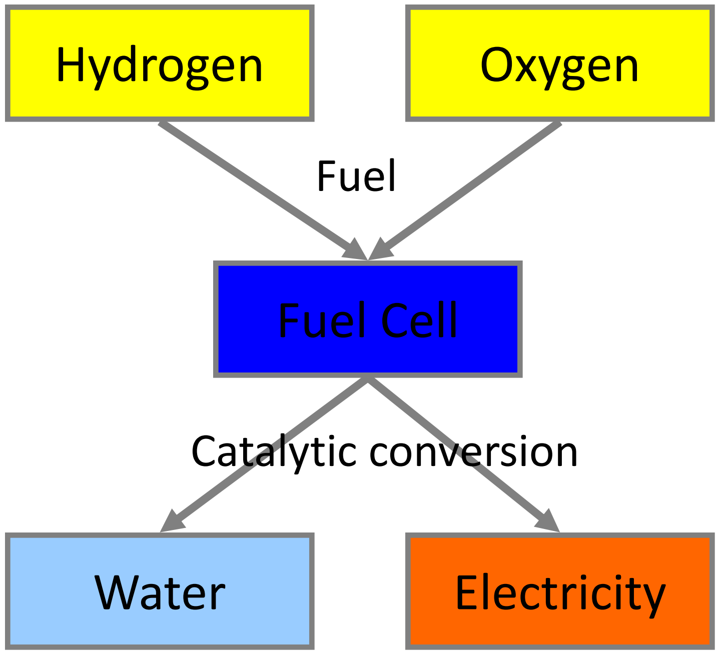
# Nuclear Power

- Nuclear waste disposal
  - Problem of nuclear waste disposal; radioactivity.
  - Low level wastes:
    - Material used to handle the highly radioactive parts of nuclear reactors .
    - Water pipes and radiation suits.
    - Lose their radioactivity after 10 to 50 years.
  - High level wastes:
    - Includes uranium, plutonium, and other highly radioactive elements made during fission.
    - Nuclear wastes have a half-life about of 10,000 to 20,000 years.
    - Requirements of long-term storage in a geologically stable area.
    - Long Term Geological Storage site at Yucca Mountain.

# Alternative Energy Resources

- What new sources of energy are likely to satisfy future demands?
- 1. Context
- 2. Hydrogen and Fuel Cells
- 3. Solar Energy
- 4. Wind Energy
- 5. Geothermal Energy
- 6. Biomass Fuels

# Hydrogen and Fuel Cells

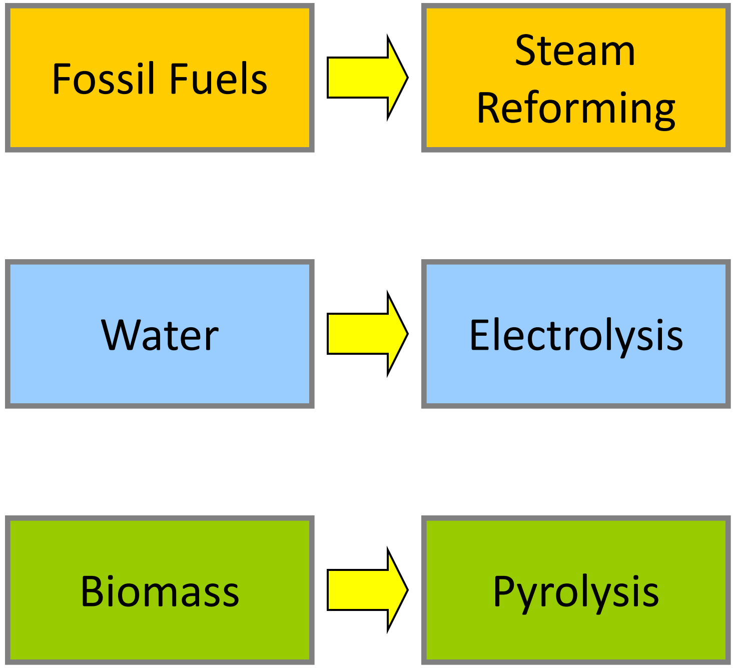



- Hydrogen
  - Considered to be the cleanest fuel.
  - Compose 90% of the matter of the universe.
  - Non polluting (emits only water and heat).
  - Highest level of energy content.
- Fuel cells
  - Convert fuel energy (such as hydrogen) to electric energy.
  - No combustion is involved.
  - Composed of an anode and a cathode.
    - Fuel is supplied to the anode.
    - Oxygen is supplied to the cathode.
    - Electrons are stripped from a reaction at the anode and attracted to form another reaction at the cathode.

# Hydrogen and Fuel Cells

- Fuel cell cars
  - Most likely replacement for the internal combustion engine.
  - Efficiency levels are between 55% and 65%.
  - May be introduced by 2004 (working prototypes).
  - Mass produced by 2010.
- Storage issues
  - Hydrogen is a highly combustive gas.
  - Find a way to safely store it, especially in a vehicle.
- Delivery issues
  - Distribution from producers to consumers.
  - Production and storage facilities.
  - Structures and methods for transporting hydrogen.
  - Fueling stations for hydrogen-powered applications.

# Hydrogen and Fuel Cells

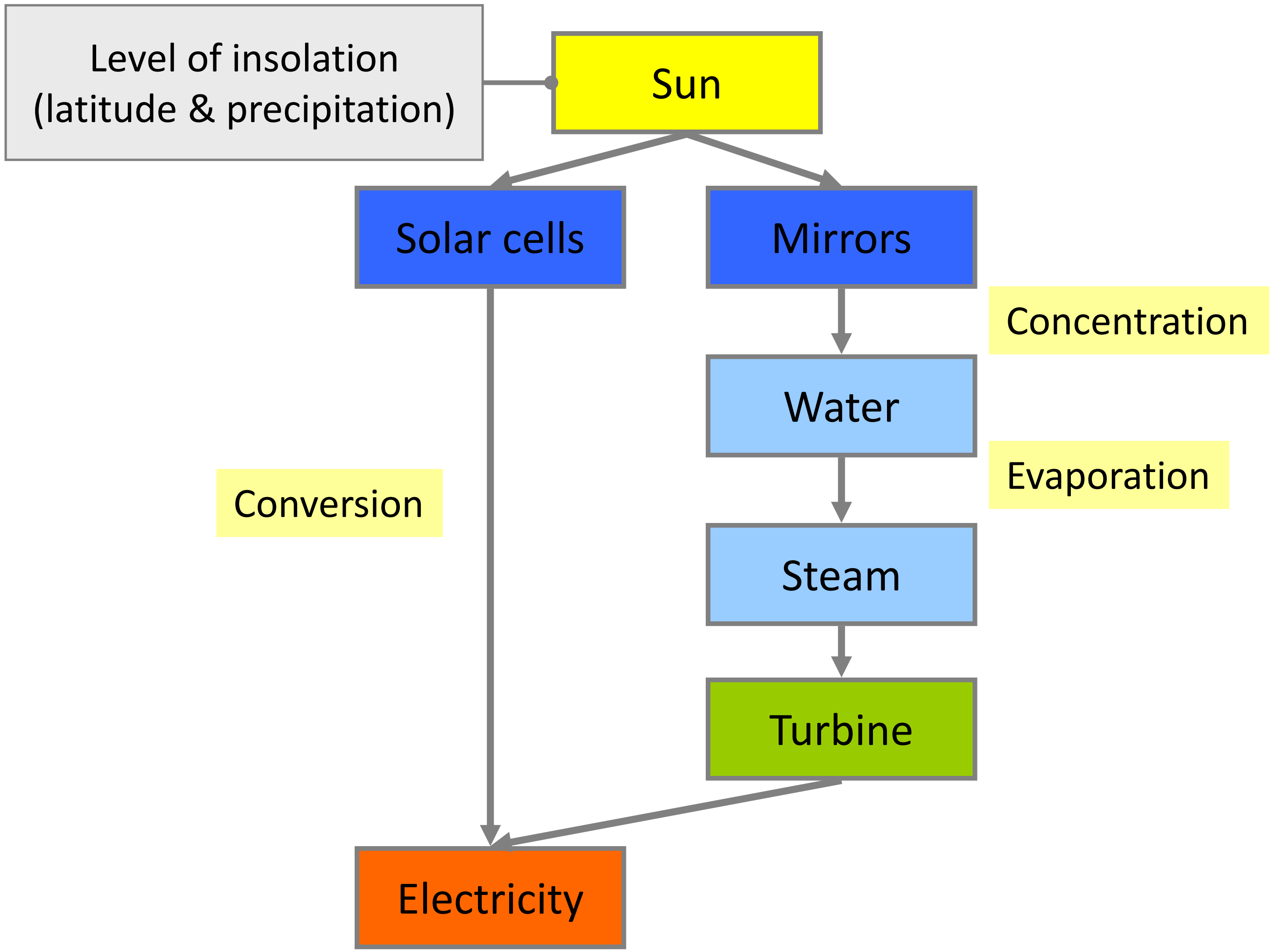



- Hydrogen production
  - Not naturally occurring.
  - Producing sufficient quantities to satisfy the demand.
  - Extraction from fossil fuels:
    - From natural gas.
    - Steam reforming.
  - Electrolysis of water:
    - Electricity from fossil fuels not a environmentally sound alternative.
    - Electricity from solar or wind energy is a better alternative.
  - Pyrolysis of the biomass:
    - Decomposing by heat in an oxygen-reduced atmosphere.

# Solar Energy

- Definition
  - Radiant energy emitted by the sun (photons emitted by nuclear fusion).
  - Conversion of solar energy into electricity.
- Photovoltaic systems
- Solar thermal systems

# Solar Energy



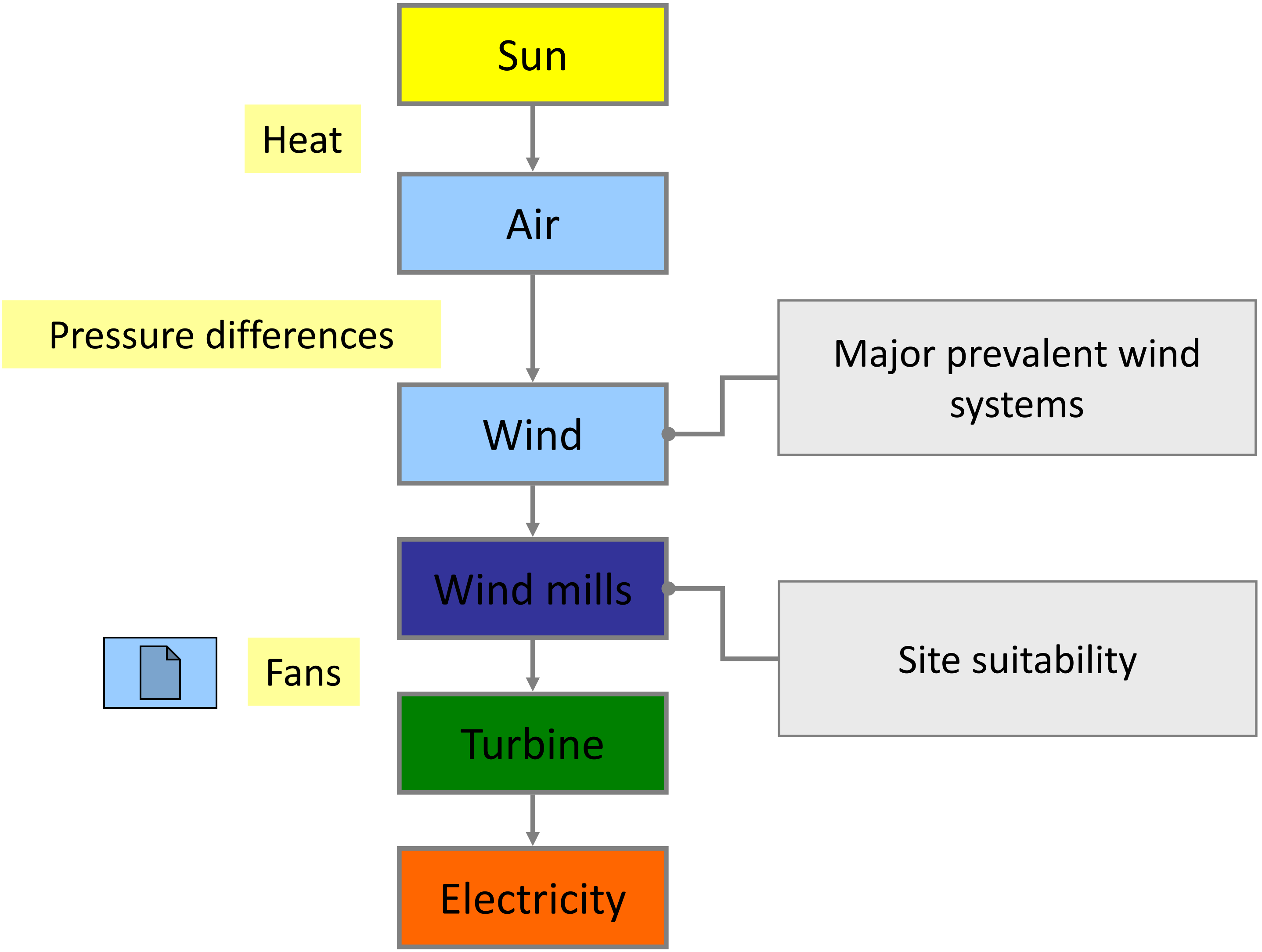
# Solar Energy

- Photovoltaic systems
  - Semiconductors to convert solar radiation into electricity.
  - Better suited for limited uses such as pumping water that do not require large amounts of electricity.
  - Costs have declined substantially:
    - 5 cents per kilowatt-hour.
    - Compared to about 3 cents for coal fired electrical power.
  - Economies of scale could then be realized in production of the necessary equipment.
  - Japan generates about 50% of the world’s solar energy.

# Solar Energy

- Solar thermal systems
  - Employ parabolic reflectors to focus solar radiation onto water pipes, generating steam that then power turbines.
  - Costing about 5-10 cents per Kwh.
  - Require ample, direct, bright sunlight.
  - Drawback of the solar thermal systems is their dependence on direct sunshine, unlike the photovoltaic cells.
- Limitations
  - Inability to utilize solar energy effectively.
  - There is currently only about a 15% conversion rate of solar energy into electricity.
  - Low concentration of the resource.
  - Need a very decentralized infrastructure to capture the resource.

# Wind Power



Sun
Heat
Air
Pressure differences
Wind
Major prevalent wind systems
Wind mills
Site suitability
Fans
Turbine
Electricity

# Wind Power

- Potential use
  - Growing efficiency of wind turbines.
  - 75% of the world's usage is in Western Europe:
    - Provided electricity to some 28 million Europeans in 2002.
    - Germany, Denmark (18%) and the Netherlands.
  - New windfarms are located at sea along the coast:
    - The wind blows harder and more steadily.
    - Does not consume valuable land.
    - No protests against wind parks marring the landscape.
  - United States:
    - The USA could generate 25% of its energy needs from wind power by installing wind farms on just 1.5% of the land.
    - North Dakota, Kansas, and Texas have enough harnessable wind energy to meet electricity needs for the whole country.

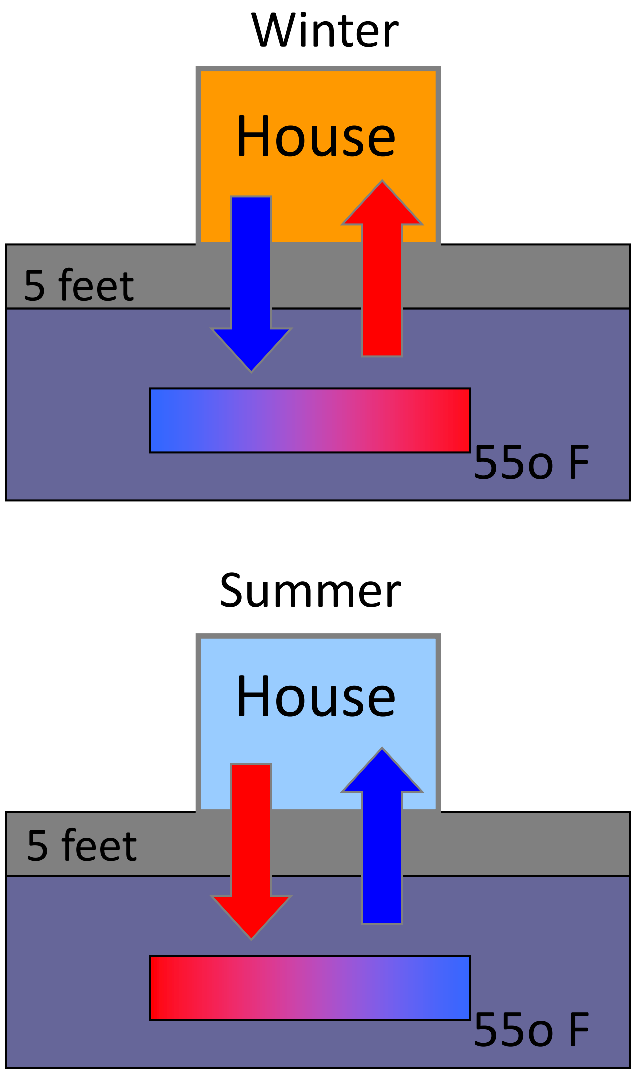
# Wind Power

- Farms are a good place to implement wind mills:
  - A quarter of a acre can earn about $2,000 a year in royalties from wind electricity generation.
  - That same quarter of an acre can only generate $100 worth or corn.
  - Farmland could simultaneously be used for agriculture and energy generation.
  - Wind energy could be used to produce hydrogen.
- Limitations
  - Extensive infrastructure and land requirements.
    - 1980: 40 cents per kwh.
    - 2001: 3-4 cents per kwh.
  - Less reliable than other sources of energy.
  - Inexhaustible energy source that can supply both electricity and fuel.

# Geothermal Energy

- Hydrogeothermal
  - 2-4 miles below the earth's surface, rock temperature well above boiling point.
  - Closely associated with tectonic activity.
  - Fracturing the rocks, introducing cold water, and recovering the resulting hot water or steam which could power turbines and produce electricity.
  - Areas where the natural heat of the earth’s interior is much closer to the surface and can be more readily tapped.

# Geothermal Energy




- Geothermal heat pumps
  - Promising alternative to heating/cooling systems.
  - Ground below the frost line (about 5 feet) is kept around 55oF year-round.
  - During winter:
    - The ground is warmer than the outside.
    - Heat can be pumped from the ground to the house.
  - During summer:
    - The ground is cooler than the outside.
    - Heat can be pumped from the house to the ground.

# Biomass

- Nature
  - Biomass energy involves the growing of crops for fuel rather than for food.
  - Crops can be burned directly to release heat or be converted to useable fuels such methane, ethanol, or hydrogen.
  - Has been around for many millennia.
  - Not been used as a large-scale energy source:
    - 14% of all energy used comes from biomass fuels.
    - 65% of all wood harvested is burned as a fuel.
    - 2.4 billion people rely on primitive biomass for cooking and heating.
  - Important only in developing countries.
    - Asia and Africa: 75% of wood fuels use.
    - US: 5% comes from biomass sources.

# Biomass

- Biofuels
    - Fuel derived from organic matter.
    - Development of biomass conversion technologies:
        - Alcohols and methane the most useful.
        - Plant materials like starch or sugar from cane.
        - Waste materials like plant stalks composed of cellulose.
- Potential and drawbacks
    - Some 20% of our energy needs could be met by biofuels without seriously compromising food supplies.
    - Competing with other agricultural products for land.

# Basics of Thermodynamics

## Thermodynamics

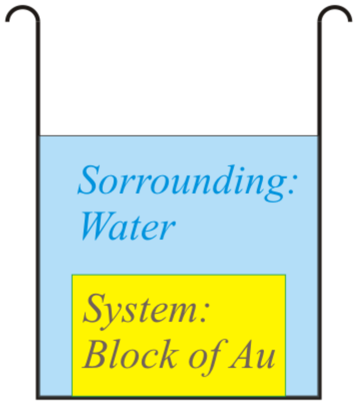
- The word thermodynamics comes from the Greek word thermos which means heat and dynamics which means power.
- Thermodynamics is concerned with the mathematical modeling of the real world.
- Thermodynamics is a branch of physics which deals with the energy and work of a system.
- In other words, thermodynamics is a science which studies the changes in temperature, pressure, and volume on physical systems on the macroscopic scale by analysing the collective motion of their particles through observation and statistics.
- it describes how thermal energy is converted to and from other forms of energy and how it affects.

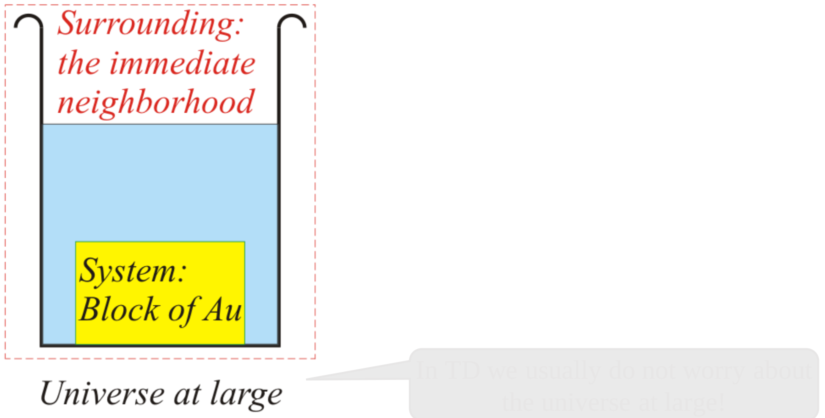
## Thermodynamics versus Kinetics

- Thermodynamics deals with stability of systems. It tells us '*what should happen?*'. '*Will it actually happen(?)*' is not the domain of thermodynamics and falls under the realm of kinetics.
- At –5°C at 1 atm pressure, ice is more stable than water. Suppose we cool water to –5°C. "Will this water freeze?" (& "how long will it take for it to freeze?") is (are) not questions addressed by thermodynamics.

# The language of TD

- To understand the laws of thermodynamics and how they work, first we need to get the terminology right. Some of the terms may look familiar (as they are used in everyday language as well)- but their meanings are *more 'technical' and 'precise',* when used in TD and hence we should not use them 'casually'.
- System is region where we focus our attention *(Au block in figure)*.
- Surrounding is the rest of the universe *(the water bath at constant 'temperature')*.
- Universe = System + Surrounding (the part that is within the dotted line box in the figure below)
- More practically, we can consider the 'Surrounding' as the immediate neighbourhood of the system (the part of the universe at large, with which the system 'effectively' interacts). In this scheme of things we can visualize: a system, the surrounding and the universe at large.
- Things that matter for the surrounding: (i) T, (ii) P, (iii) ability to: do work, transfer heat, transfer matter, etc. Parameters for the system: (i) Internal energy, (ii) Enthapy, (iii) T, (iv) P, (v) mass, etc.

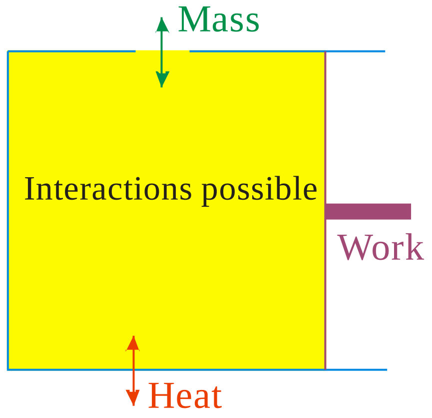


# Open, closed and isolated systems

- To a thermodynamic system two 'things' may be added/removed:
  - **energy** *(in the form of heat &/or work)* ➢ **matter**.
- An **open system** is one to which you can add/remove matter (e.g. a open beaker to which we can add water). When you add matter- you also end up adding heat (which is contained in that matter).
- A system to which you cannot add matter is called **closed**.
  Though you cannot add/remove matter to a closed system, *you can still add/remove heat* (you can cool a closed water bottle in fridge).
- A system to which *neither matter nor heat* can be added/removed is called **isolated**.
  A closed vacuum 'thermos' flask can be considered as isolated.

| Type of boundary | Interactions |
|---|---|
| Open | All interactions possible (Mass, Work, Heat) |
| Closed | Matter cannot enter or leave |
| Semi-permeable | Only certain species can enter or leave |
| Insulated | Heat cannot enter or leave |
| Rigid | Mechanical work cannot be done* |
| Isolated | No interactions are possible** |




** By or on the system*
*** Mass, Heat or Work*

- Matter is easy to understand and includes atoms, ions, electrons, etc.
- Energy may be transferred ('added') to the system as heat, electromagnetic radiation etc.
- In TD the two modes of transfer of energy to the system considered are Heat and Work.
  - Heat and work are modes of transfer of energy and not 'energy' itself.
  - *Once inside the system, the part which came via work and the part which came via heat, cannot be distinguished*
  - *Before the start of the process and after the process is completed, the terms heat and work are not relevant.*
- From the above it is clear that, *bodies contain internal energy and not heat (nor work!).*
- Matter when added to a system brings along with it some energy. The 'energy density' (energy per unit mass or energy per unit volume) in the incoming matter may be higher or lower than the matter already present in the system.

## Processes in TD

*We will deal with some of them in detail later on*

- Here is a brief listing of a few kinds of processes, which we will encounter in TD:
  - Isothermal process → the process takes place at constant temperature
    *(e.g. freezing of water to ice at –10 ℃)*
  - Isobaric → constant pressure
    *(e.g. heating of water in open air→ under atmospheric pressure)*
  - Isochoric → constant volume
    *(e.g. heating of gas in a sealed metal container)*
  - Reversible process → the system is close to equilibrium at all times (and *infinitesimal alteration* of the conditions can restore the universe (system + surrounding) to the original state. *(Hence, there are no truly reversible processes in nature).*
  - Cyclic process → the final and initial state are the same. However, q and w need not be zero.
  - Adiabatic process → $dq$ is zero during the process (no heat is added/removed to/from the system)
- A combination of the above are also possible: e.g. 'reversible adiabatic process'.

# Heat and Work

- Work (W) in mechanics is displacement (d) against a resisting force (F). $W = F \times d$
- Work has units of energy (Joule, J).
- Work can be expansion work ($P\Delta V$), electrical work, magnetic work etc. *(many sets of stimuli and their responses).*
- Heat as used in TD is a **tricky term** *(yes, it is a very technical term as used in TD).*
  - The transfer of energy as a result of a temperature difference is called heat.
  - "In TD heat is NOT an entity or even a form of energy; heat is a mode of transfer of energy"
  - "Heat is the transfer of energy by virtue of a temperature difference"
  - "Heat is the name of a process, not the name of an entity"
  - "Bodies contain internal energy (U) and not heat"
- The 'flow' of energy down a temperature gradient can be treated mathematically by considering heat as a mass-less fluid → this does not make heat a fluid!

- Work is coordinated flow of matter.
  - Lowering of a weight can do work
  - Motion of piston can do work
  - Flow of electrons in conductor can do work.
- Heat involves random motion of matter (or the constituent entities of matter).
  - Like gas molecules in a gas cylinder
  - Water molecules in a cup of water
  - Atoms vibrating in a block of Cu.

- Energy may enter the system as heat or work.
- Once inside the system:

  • it does not matter how the energy entered the system* (i.e. work and heat are terms associated with the surrounding and once inside the system there is no 'memory' of how the input was received and

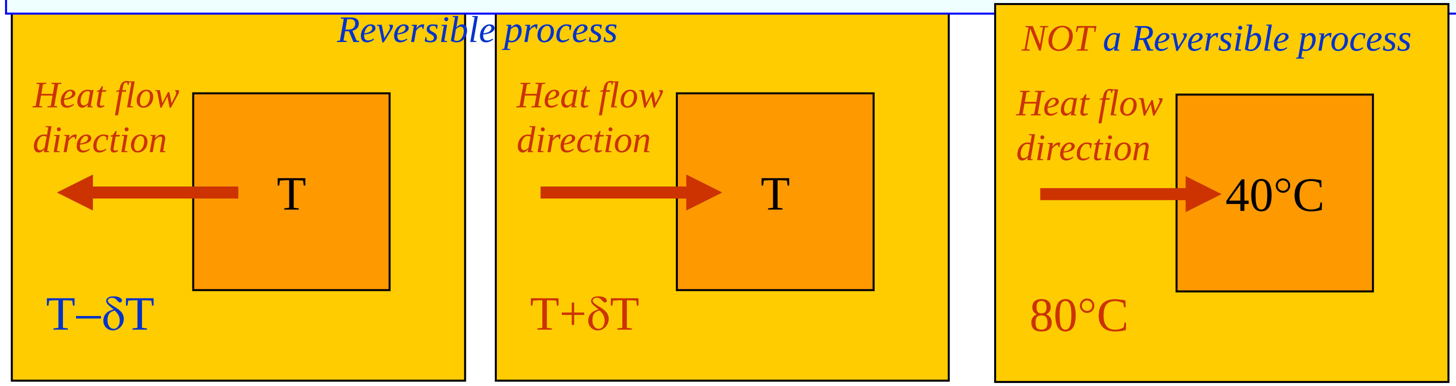
  • the energy is stored as potential energy (PE) and kinetic energy (KE).
- This energy can be withdrawn as work or heat from the system.

** As Aktins put it: "money may enter a back as cheque or cash – but once inside the bank there is no difference".*

# Reversible process

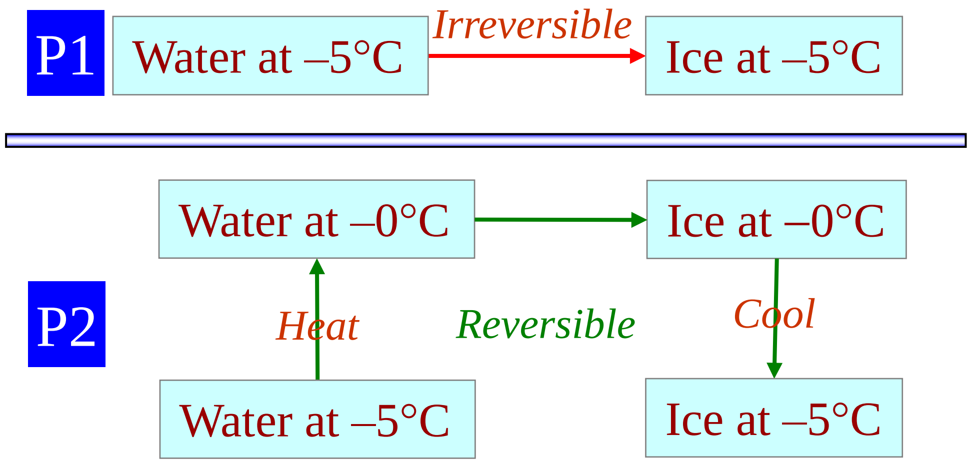
*'Reversible' is a technical term (like many others) in the context of TD.*

- A reversible process is one where an infinitesimal change in the conditions of the surroundings leads to a 'reversal' of the process. (The system is very close to equilibrium and infinitesimal changes can restore the system and surroundings to the original state).
- If a block of material (at T) is in contact with surrounding at (T–δT), then 'heat will flow' into the surrounding. Now if the temperature of the surrounding is increased to (T+δT), then the direction of heat flow will be reversed.
- If a block of material (at 40°C) is contact with surrounding at 80°C then the 'heat transfer' with takes place is not reversible.
- Though the above example uses temperature differences to illustrate the point, the situation with other stimuli like pressure (differences) is also identical.
- Consider a piston with gas in it a pressure 'P'. If the external pressure is (P+δP), then the gas (in the piston) will be compressed (slightly). The reverse process will occur if the external (surrounding pressure is slightly lower).
- Maximum work will be done if the compression (or expansion) is carried out in a reversible manner.



# How to visualize a ‘reversible’ equivalent to a ‘irreversible’ processes?

- Let us keep one example in mind as to how we can (sometimes) construct a ‘reversible’ equivalent to a ‘irreversible’ processes.
- Let us consider the example of the freezing of ‘undercooled water’* at –5°C (at 1 atm pressure). This freezing of undercooled water is irreversible (P1 below).
- We can visualize this process as taking place in three reversible steps ➢ hence making the entire process reversible (P2 below).




* *‘Undercooled’ implies that the water is held in the liquid state below the bulk freezing point! How is this possible?→ read chapter on phase transformations*

## The First Law

- The internal energy of an isolated system is constant. A closed system may exchange energy as heat or work. Let us consider a close system at rest without external fields.
- There exists a state function U such that for any process in a closed system:

  $\mathbf{\Delta U = q + w}$ [1] (For an infinitesimal change: $dU = (U_2 - U_1) = \delta q + \delta w$)

  - q → heat flow into the system
  - w, W → work done on the system *(work done by the system is negative of above- this is just 'one' sign convention)*
- U is the internal energy. Being a state function for a process ΔU depends only of the final and initial state of the system. $\Delta U = U_{final} - U_{initial}$. Hence, for an infinitesimal process it can be written as dU.
  - In contrast to U, q & w are NOT state functions (i.e. depend on the path followed).
  - δq and δw have to be evaluated based on a path dependent integral.
- For an infinitesimal process eq. [1] can be written as: $dU = \delta q + \delta w$
- The change in U of the surrounding will be opposite in sign, such that:

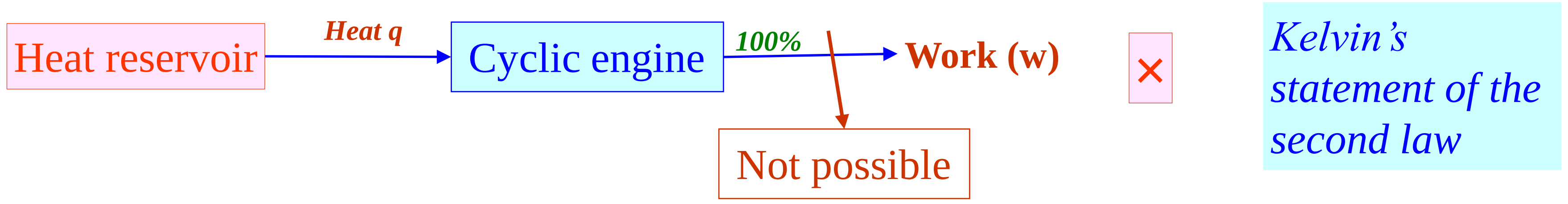
  $\Delta U_{system} + \Delta U_{surrounding} = 0$
- Actually, it should be ΔE above and not ΔU {however, in many cases K and V are zero (e.g. a system at rest considered above) and the above is valid- as discussed elsewhere}.
- It is to be noted that in 'w' work done by one part of the system on another part is not included.

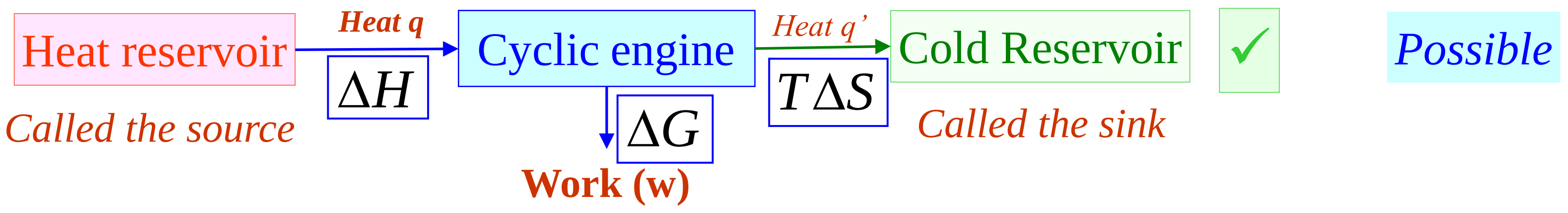
* Depending on the sign convention used there are other ways of writing the first law:
$dU = \delta q - \delta W$, $dU = -\delta q + \delta W$

## The Second Law

*The second law comes in many equivalent forms*

- It is impossible to build a cyclic machine* that converts heat into work with 100% efficiency → Kelvin's statement of the second law.
- Another way of viewing the same:
  it is impossible to construct a cyclic machine** that completely (with 100% efficiency) converts heat, which is energy of *random molecular motion*, to mechanical work, which is *ordered motion*.
- The unavailable work is due to the role of Entropy in the process.



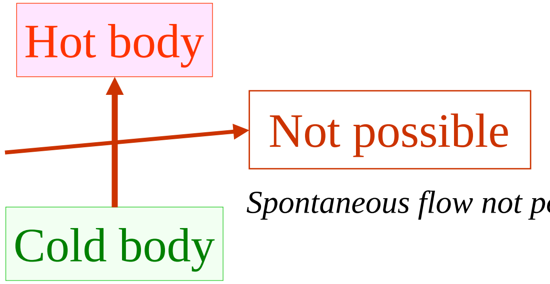




* *For now we are 'building' 'conceptual machines'!*

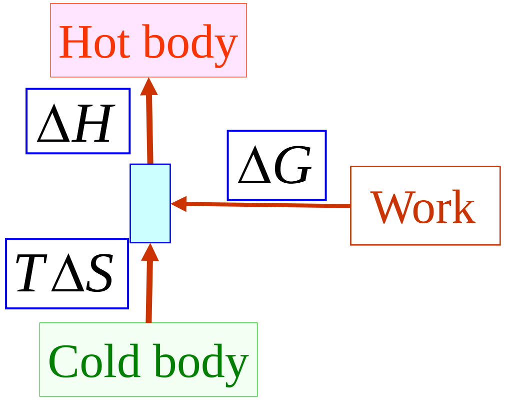
** *These 'engines' which use heat and try to produce work are called heat engines.*

*Another statement of the second law → the Clausius statement*

- Heat does not 'flow*' from a colder body to a hotter body, without an concomitant change outside of the two bodies→ Clausius's statement of the second law.(a)
- This automatically implies that the spontaneous direction of the 'flow of heat*' is from a hotter body to a colder body.(b)
- The Kelvin's and Clausius's statements of the second law are equivalent. I.e. if we violate Kelvin's statement, then we will automatically violate the Clausius's statement of the second law (and vice-versa).




*Spontaneous flow not possible*




* *Used here in the 'common usage sense'.*

(b) is obvious, but not (a) → though they represent the same fact.

*A combined (Kelvin + Clausius) statement of the II Law*

- The entropy* of a closed system will increase during any spontaneous change/process.

  *If we consider the Universe to be a closed system (without proof!!)**, then,*

- the entropy of the universe will increase during any spontaneous change (process).

*You may want to jump to chapter on equilibrium to know about Entropy first*

*Entropy sets the direction for the arrow of time !*

** Soon we will get down to this mysterious quantity.*

*** For all we know the Universe could be 'leaky' with wormholes to other parallel Universes!*

# The efficiency of a heat engine

- The efficiency of a heat engine is the amount of work output divided by the amount of heat input.
- This efficiency depends only on the ratio of the temperature of the sink to the temperature of the source. The maximum efficiency achievable is given by the formula below.
- This is surprising as:
  - there is no mention of the medium of the system (or its properties),
  - the formula has only temperatures and
  - the temperature of the sink seems to play a major role (as the presence of the sink is usually not intentional or obvious→ in a steam engine sink is the air around the engine and source is the hot steam).

  Important message➢ Sink *(characterized by its temperature)* is as important as the source.
- To increase the maximum possible efficiency of a heat engine, either the temperature of the source has to be increased on the temperature of the sink has to be decreased.

$$\eta_{heat\ engine} = \frac{w_{output}}{q_{input}}$$

$$\eta^{\mathrm{max}}_{heat\ engine} = 1 - \left(\frac{T_{\mathrm{sink}}}{T_{\mathrm{source}}}\right)$$

*"Reflections on the Motive Power of Fire", Chapman & Hall ltd, London, 1897.*

*Nicolas Léonard Sadi Carnot in 1824.*

*Clausius statement of the second law*

- Heat cannot spontaneously flow from a cold (low temperature) body to a hot body.
- To make heat flow from a cold body to a hot body, there must be accompanying change elsewhere (work has to be done to achieve this).

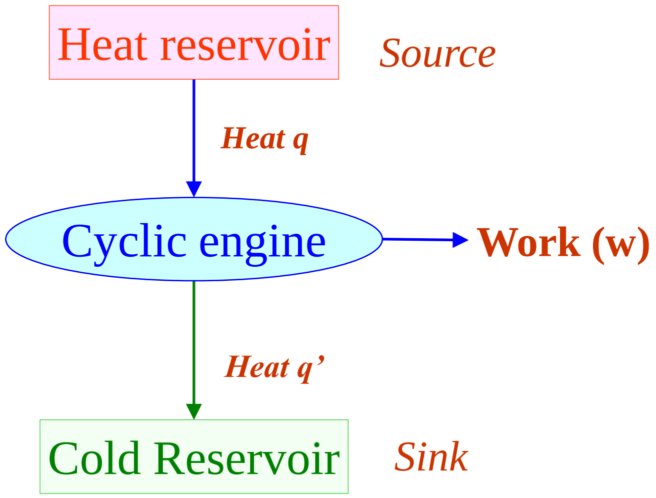
Q & A

What is the difference between ‘heat engine’ and ‘work engine’?

- Actually both the engines we are going to describe here are usually known as heat engines.
- We are differentiating two types of engines to see which one produces work and which one actually transfers heat.
- In the heat engine as the temperature of the cold body tends to zero Kelvin, more and more work has to be done to transfer the heat from the cold body to the hot body.

‘Work engine’

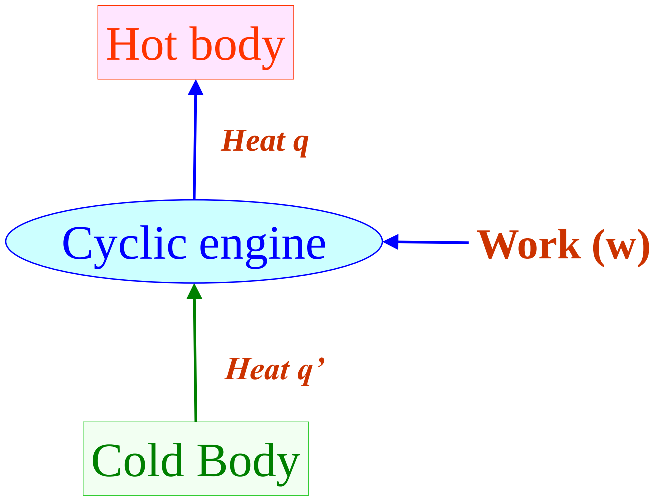
Like a steam engine




*The main objective here is to produce work*

‘heat engine’

Like a refrigerator




*The main objective here is to transfer heat from a cold body to a hot body*

## The Third Law

- For substances in internal equilibrium, undergoing an isothermal process, the entropy change goes to zero as T (in K) goes to zero.

$$\lim_{T \to 0} \Delta S = 0$$

- The law is valid for pure substances and mixtures.
- Close to Zero Kelvin, the molecular motions have to be treated using quantum mechanics → still it is found that quantum ideal gases obey the third law.

Phenomenological description of the third law.

- There does not exist any finite sequence of cyclical process, which can cool a body to zero Kelvin (absolute zero).

Other statements of the third law.

- For a closed system in thermodynamic equilibrium, the entropy of the system approaches a *constant value* as the temperature goes to absolute zero.

# Ideal and Perfect Gases

- To understand the basics often we rely on simple ‘test-bed’ systems.
- In TD one such system is the ideal gas. In an ideal gas the *molecules do not interact with each other* (Noble gases come close to this at normal temperatures).
  An ideal gas obeys the equation of state: $\boxed{PV = nRT}$
- As the molecules of a ideal gas do not interact with each other, the internal energy of the system is expected to be ‘NOT dependent’ on the volume of the system.
  I.e.: $\boxed{\left(\frac{\partial U}{\partial V}\right)_T = 0}$
- A gas which obeys both the above equations is called a **perfect gas**.
- Internal energy (a state function) is normally a function of T & V: U = U(T,V).
  - For a perfect gas: U = U(T) only.

Humorous look at the three laws

- The first law says: "you cannot win".
- The second law says: "you can at best break even- that too at zero Kelvin".
- Third law says: "zero Kelvin is unattainable".

# GDP

# Micro vs. Macro

- ***Microeconomics***:
  The study of how individual households and firms make decisions, interact with one another in markets.
- ***Macroeconomics***:
  The study of the economy as a whole.
- We begin our study of macroeconomics with the country's total income and expenditure.

# Income and Expenditure

- **Gross Domestic Product (GDP)** measures total income of everyone in the economy.
- GDP also measures total expenditure on the economy's output of g&s.

*For the economy as a whole,*
***income equals expenditure***
*because every dollar a buyer spends*
*is a dollar of income for the seller.*

# The Circular-Flow Diagram

- a simple depiction of the macroeconomy
- illustrates GDP as spending, revenue, factor payments, and income
- Preliminaries:
  - **Factors of production** are inputs like labor, land, capital, and natural resources.
  - **Factor payments** are payments to the factors of production (*e.g.*, wages, rent).

**Households**:

- own the factors of production, sell/rent them to firms for income
- buy and consume goods & services

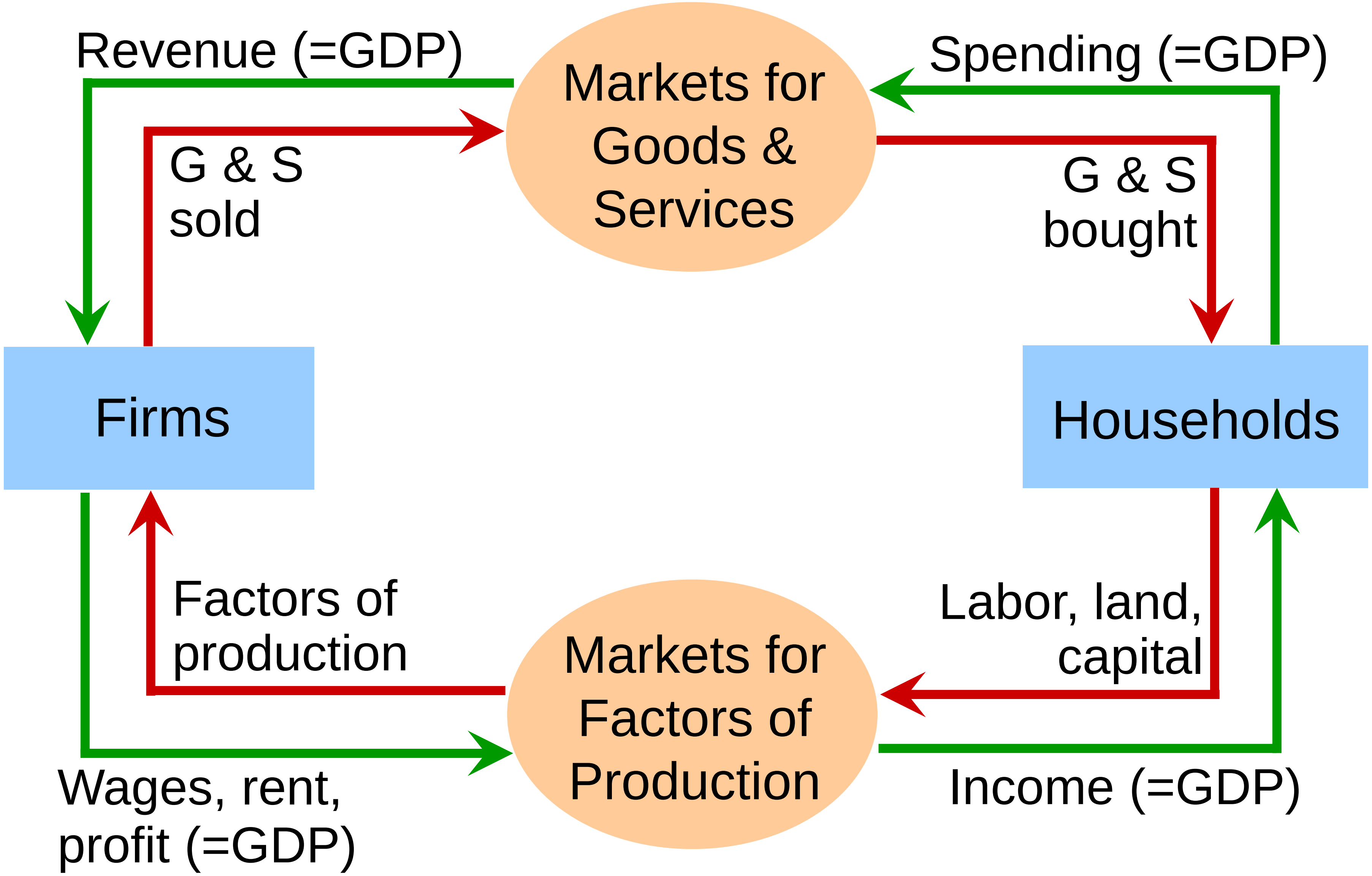
Firms

Households

**Firms**:

- buy/hire factors of production, use them to produce goods and services
- sell goods & services

The Circular-Flow Diagram



# What This Diagram Omits

- The government
  - collects taxes, buys g&s
- The financial system
  - matches savers' supply of funds with borrowers' demand for loans
- The foreign sector
  - trades g&s, financial assets, and currencies with the country's residents

# Gross Domestic Product (GDP) Is…

…the market value of all final goods & services

produced within a country

in a given period of time.

---

*Goods are valued at their market prices, so:*

- *All goods measured in the same units (e.g., dollars in the U.S.)*
- *Things that don't have a market value are excluded, e.g., housework you do for yourself.*

Gross Domestic Product (GDP) Is…

…the market value of all final goods & services
produced within a country
in a given period of time.

---

***Final goods**: intended for the end user*

***Intermediate goods**: used as components or ingredients in the production of other goods*

*GDP only includes final goods – they already embody the value of the intermediate goods used in their production.*

# Gross Domestic Product (GDP) Is…

…the market value of all final goods & services
produced within a country
in a given period of time.

---

*GDP includes tangible goods*
*(like DVDs, mountain bikes, beer)*

*and intangible services*
*(dry cleaning, concerts, cell phone service).*

# Gross Domestic Product (GDP) Is…

…the market value of all final goods & services

produced within a country

in a given period of time.

---

*GDP includes currently produced goods,*
*not goods produced in the past.*

# Gross Domestic Product (GDP) Is…

…the market value of all final goods & services produced within a country in a given period of time.

---

*GDP measures the value of production that occurs within a country’s borders, whether done by its own citizens or by foreigners located there.*

# Gross Domestic Product (GDP) Is…

…the market value of all final goods & services
produced within a country
in a given period of time.

---

*Usually a year or a quarter (3 months)*

# The Components of GDP

- Recall: GDP is total spending.
- Four components:
  - Consumption (**C**)
  - Investment (**I**)
  - Government Purchases (**G**)
  - Net Exports (**NX**)
- These components add up to GDP (denoted **Y**):

$$\mathbf{Y = C + I + G + NX}$$

# Consumption (C)

- is total spending by households on g&s.
- Note on housing costs:
  - For renters,
    consumption includes rent payments.
  - For homeowners,
    consumption includes the imputed rental value of the house, but not the purchase price or mortgage payments.

# Investment (I)

- is total spending on goods that will be used in the future to produce more goods.
- includes spending on
  - capital equipment (*e.g.*, machines, tools)
  - structures (factories, office buildings, houses)
  - inventories (goods produced but not yet sold)

*Note:* ***"Investment"*** *does not mean the purchase of financial assets like stocks and bonds.*

# Government Purchases (G)

- is all spending on the g&s purchased by govt at the federal, state, and local levels.
- **G** excludes **transfer payments**, such as Social Security or unemployment insurance benefits.

  They are not purchases of g&s.

# Net Exports (NX)

- **NX** = exports – imports
- Exports represent foreign spending on the economy's g&s.
- Imports are the portions of **C**, **I**, and **G** that are spent on g&s produced abroad.
- Adding up all the components of GDP gives:

$$\mathbf{Y = C + I + G + NX}$$

# U.S. GDP and Its Components, 2009

| | *billions* | *% of GDP* | *per capita* |
|---|---|---|---|
| **Y** | $14,242 | 100.0 | $46,299 |
| **C** | 10,133 | 71.1 | 32,940 |
| **I** | 1,556 | 10.9 | 5,059 |
| **G** | 2,955 | 20.8 | 9,608 |
| **NX** | –402 | –2.8 | –1,307 |

# ACTIVE LEARNING *1*
## GDP and its components

In each of the following cases, determine how much GDP and each of its components is affected (if at all).

**A.** Debbie spends $200 to buy her husband dinner at the finest restaurant in Boston.

**B.** Sarah spends $1800 on a new laptop to use in her publishing business. The laptop was built in China.

**C.** Jane spends $1200 on a computer to use in her editing business. She got last year's model on sale for a great price from a local manufacturer.

**D.** General Motors builds $500 million worth of cars, but consumers only buy $470 million worth of them.

## ACTIVE LEARNING *1*
# Answers

**A.** Debbie spends $200 to buy her husband dinner at the finest restaurant in Boston.

*Consumption and GDP rise by $200.*

**B.** Sarah spends $1800 on a new laptop to use in her publishing business. The laptop was built in China.

*Investment rises by $1800, net exports fall by $1800, GDP is unchanged.*

## ACTIVE LEARNING *1*
# Answers

**C.** Jane spends $1200 on a computer to use in her editing business. She got last year's model on sale for a great price from a local manufacturer.

*Current GDP and investment do not change, because the computer was built last year.*

**D.** General Motors builds $500 million worth of cars, but consumers only buy $470 million of them.

*Consumption rises by $470 million,*
*inventory investment rises by $30 million,*
*and GDP rises by $500 million.*

# Real versus Nominal GDP

- Inflation can distort economic variables like GDP, so we have two versions of GDP:
  One is corrected for inflation, the other is not.
- **Nominal GDP** values output using current prices. It is not corrected for inflation.
- **Real GDP** values output using the prices of a ***base year***. Real GDP is corrected for inflation.

# EXAMPLE:

| | Pizza | | Latte | |
|---|---|---|---|---|
| *year* | ***P*** | ***Q*** | ***P*** | ***Q*** |
| 2005 | $10 | 400 | $2.00 | 1000 |
| 2006 | $11 | 500 | $2.50 | 1100 |
| 2007 | $12 | 600 | $3.00 | 1200 |

Compute nominal GDP in each year:

*Increase:*

2005: $10 x 400 + $2 x 1000 = $6,000

37.5%

2006: $11 x 500 + $2.50 x 1100 = $8,250

30.9%

2007: $12 x 600 + $3 x 1200 = $10,800

# EXAMPLE:

| | Pizza | | Latte | |
|---|---|---|---|---|
| *year* | ***P*** | ***Q*** | ***P*** | ***Q*** |
| 2005 | $10 | 400 | $2.00 | 1000 |
| 2006 | $11 | 500 | $2.50 | 1100 |
| 2007 | $12 | 600 | $3.00 | 1200 |

Compute real GDP in each year, using 2005 as the base year:

***Increase:***

2005: $10 x 400 + $2 x 1000 = $6,000

20.0%

2006: $10 x 500 + $2 x 1100 = $7,200

16.7%

2007: $10 x 600 + $2 x 1200 = $8,400

# EXAMPLE:

| *year* | *Nominal GDP* | *Real GDP* |
|---|---|---|
| 2005 | $6000 | $6000 |
| 2006 | $8250 | $7200 |
| 2007 | $10,800 | $8400 |

In each year,

- nominal GDP is measured using the (then) current prices.
- real GDP is measured using constant prices from the base year (2005 in this example).

# EXAMPLE:

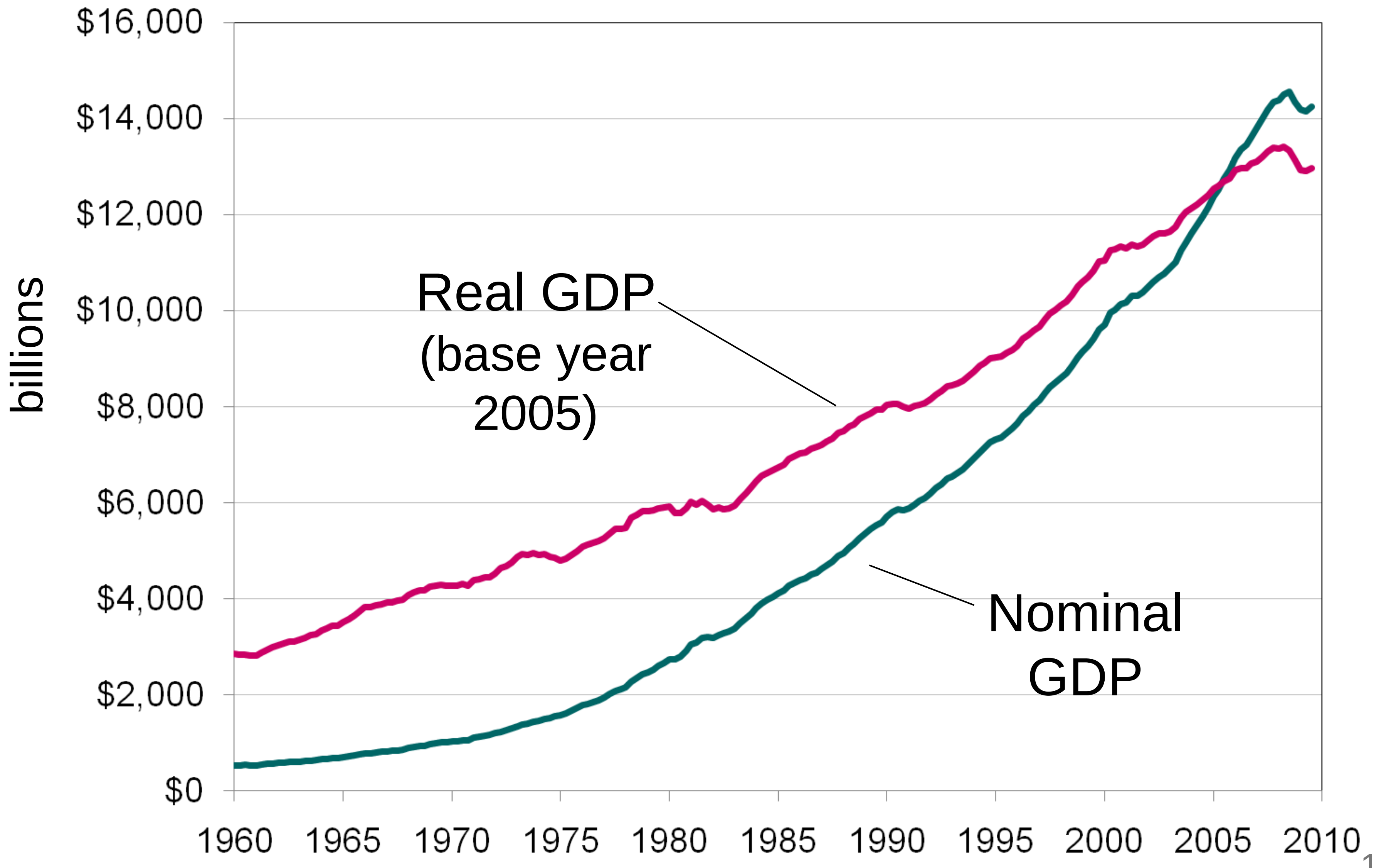
| *year* | *Nominal GDP* | | *Real GDP* | |
|---|---|---|---|---|
| 2005 | $6000 | | $6000 | |
| | | 37.5% | | 20.0% |
| 2006 | $8250 | | $7200 | |
| | | 30.9% | | 16.7% |
| 2007 | $10,800 | | $8400 | |

- The change in nominal GDP reflects both prices and quantities.

- The change in real GDP is the amount that GDP would change if prices were constant (*i.e.*, if zero inflation).

***Hence, real GDP is corrected for inflation.***

# Nominal and Real GDP in the U.S., 1965-2009



# The GDP Deflator

- The GDP deflator is a measure of the overall level of prices.
- Definition:

$$\text{GDP deflator} = 100 \times \frac{\text{nominal GDP}}{\text{real GDP}}$$

- One way to measure the economy's **inflation rate** is to compute the percentage increase in the GDP deflator from one year to the next.

# EXAMPLE:

| *year* | *Nominal GDP* | *Real GDP* | *GDP Deflator* | |
|---|---|---|---|---|
| 2005 | \$6000 | \$6000 | 100.0 | |
| | | | | 14.6% |
| 2006 | \$8250 | \$7200 | 114.6 | |
| | | | | 12.2% |
| 2007 | \$10,800 | \$8400 | 128.6 | |

Compute the GDP deflator in each year:

2005: 100 x (6000/6000) = 100.0

2006: 100 x (8250/7200) = 114.6

2007: 100 x (10,800/8400) = 128.6

## ACTIVE LEARNING 2

# Computing GDP

| | 2007 (base yr) | | 2008 | | 2009 | |
|---|---|---|---|---|---|---|
| | *P* | *Q* | *P* | *Q* | *P* | *Q* |
| Good A | $30 | 900 | $31 | 1,000 | $36 | 1050 |
| Good B | $100 | 192 | $102 | 200 | $100 | 205 |

Use the above data to solve these problems:

**A.** Compute nominal GDP in 2007.

**B.** Compute real GDP in 2008.

**C.** Compute the GDP deflator in 2009.

## ACTIVE LEARNING *2*

# Answers

| | 2007 (base yr) | | 2008 | | 2009 | |
|---|---|---|---|---|---|---|
| | *P* | *Q* | *P* | *Q* | *P* | *Q* |
| Good A | $30 | 900 | $31 | 1,000 | $36 | 1050 |
| Good B | $100 | 192 | $102 | 200 | $100 | 205 |

**A.** Compute nominal GDP in 2007.

$30 x 900 + $100 x 192 = <u>$46,200</u>

**B.** Compute real GDP in 2008.

$30 x 1000 + $100 x 200 = <u>$50,000</u>

## ACTIVE LEARNING 2
# Answers

| | 2007 (base yr) | | 2008 | | 2009 | |
|---|---|---|---|---|---|---|
| | *P* | *Q* | *P* | *Q* | *P* | *Q* |
| Good A | $30 | 900 | $31 | 1,000 | $36 | 1050 |
| Good B | $100 | 192 | $102 | 200 | $100 | 205 |

**C.** Compute the GDP deflator in 2009.

Nom GDP = $36 x 1050 + $100 x 205 = <u>$58,300</u>

Real GDP = $30 x 1050 + $100 x 205 = <u>$52,000</u>

GDP deflator = 100 x (Nom GDP)/(Real GDP)

= 100 x ($58,300)/($52,000) = <u>112.1</u>

# GDP and Economic Well-Being

- ***Real GDP per capita is the main indicator of the average person's standard of living.***
- But GDP is not a perfect measure of well-being.
- Robert Kennedy issued a very eloquent yet harsh criticism of GDP:

## Gross Domestic Product…

"… does not allow for the health of our children, the quality of their education, or the joy of their play. It does not include the beauty of our poetry or the strength of our marriages, the intelligence of our public debate or the integrity of our public officials. It measures neither our courage, nor our wisdom, nor our devotion to our country. It measures everything, in short, except that which makes life worthwhile, and it can tell us everything about America except why we are proud that we are Americans."

***- Senator Robert Kennedy, 1968***

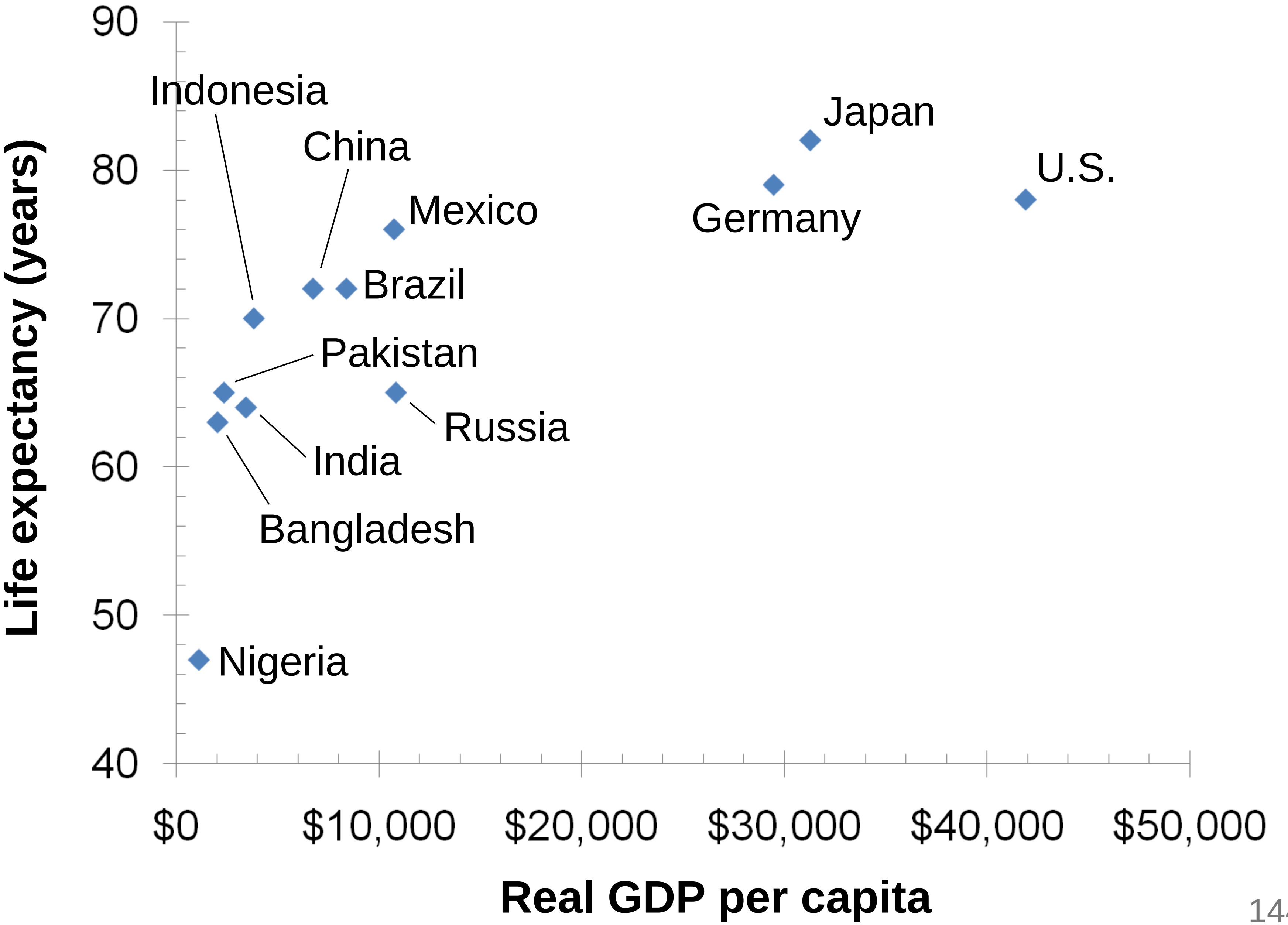
# GDP Does Not Value:

- the quality of the environment
- leisure time
- non-market activity, such as the child care a parent provides his or her child at home
- an equitable distribution of income

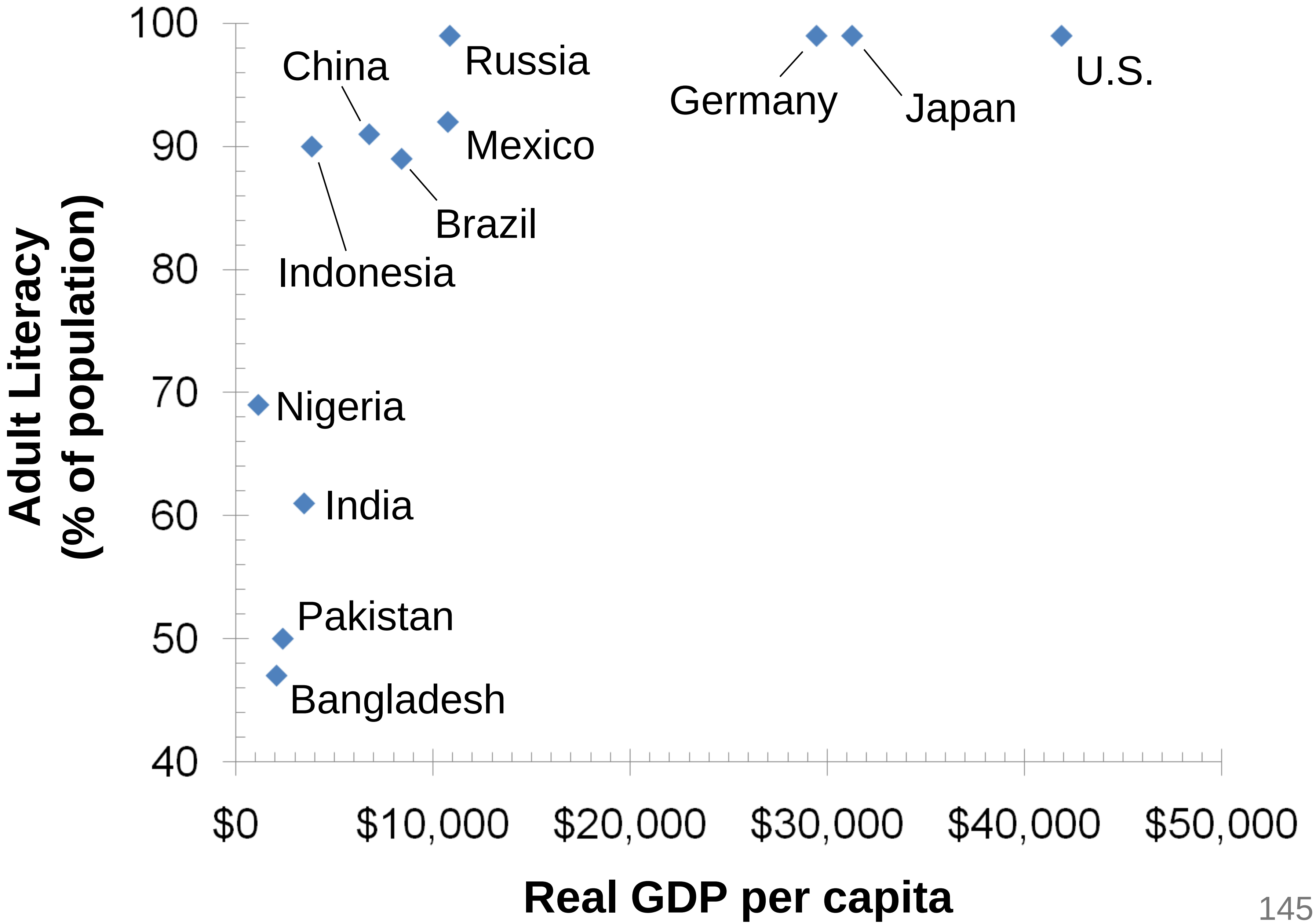
# Then Why Do We Care About GDP?

- Having a large GDP enables a country to afford better schools, a cleaner environment,
  health care, etc.
- Many indicators of the quality of life are positively correlated with GDP.  For example…

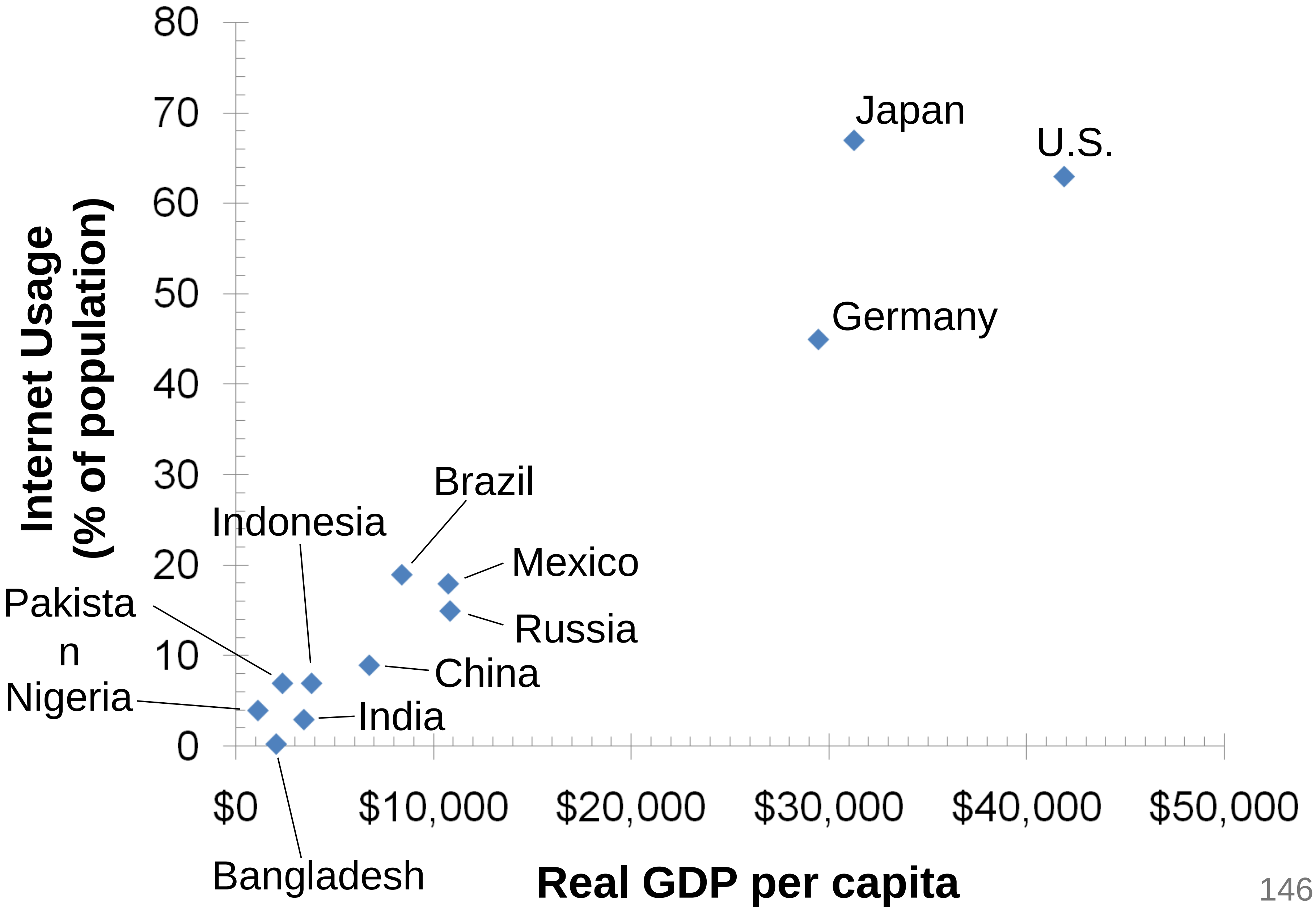
# GDP and Life Expectancy in 12 countries

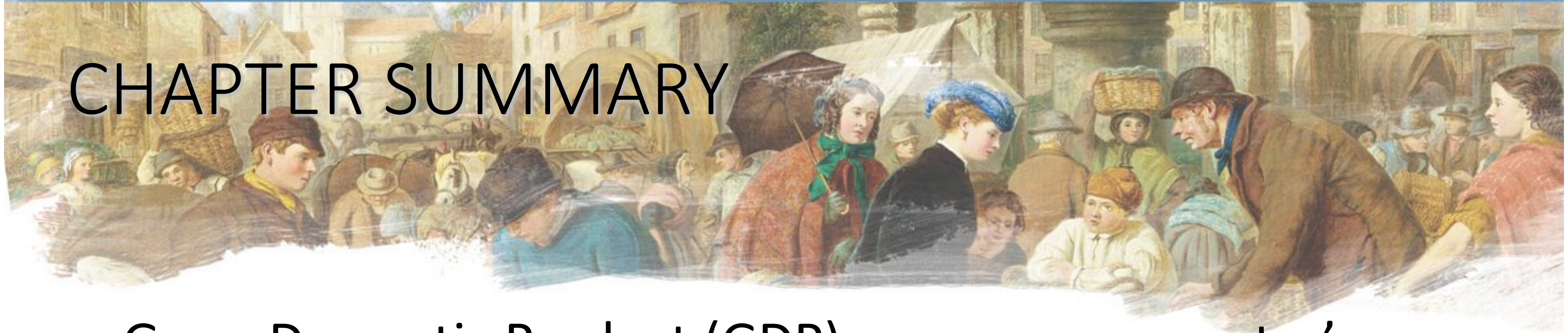


# GDP and Literacy in 12 countries



# GDP and Internet Usage in 12 countries





# CHAPTER SUMMARY

- Gross Domestic Product (GDP) measures a country’s total income and expenditure.
- The four spending components of GDP include: Consumption, Investment, Government Purchases, and Net Exports.
- Nominal GDP is measured using current prices.  Real GDP is measured using the prices of a constant base year and is corrected for inflation.
- GDP is the main indicator of a country’s economic well-being, even though it is not perfect.

# NATIONAL ENERGY POLICY

- The National Energy Policy (NEP) aims to chart the way forward to meet the Government bold ambitions for India's energy sector developments.
- This includes providing access to electricity to all the Census villages by 2018, and for universal electrification to be achieved, with 24x7 electricity by 2022
- The share of manufacturing in GDP is projected to go up to 25% from the present level of 16%, while the Ministry of Petroleum is targeting reduction of oil imports by 10% by 2022 compared to 2014-15 levels
- National Development Council (**NDC**) target reduction of emissions intensity of 33%-35% by 2030 over 2005, through increasing renewable energy capacity to 175 GW by 2022, and increase the share of non-fossil fuel based capacity in the electricity mix to above 40% by 2030.

- This is also expected to mainstream emerging energy technologies, and provide consumer energy choices
- The NEP builds on the achievements of the earlier overarching policy framework -the Integrated Energy Policy (IEP), and sets the new agenda consistent with the redefined role of emerging developments in the energy world.
- There are four key objectives to India's broad arching energy policy under the IEP:
  1. Access at affordable prices;
  2. Improved security and Independence;
  3. Greater Sustainability; and
  4. Economic Growth.

- To achieve these four objectives, seven areas of intervention were identified, of which energy efficiency is one.
  (i) Energy Consumption by businesses, households, transportation and agriculture
  (ii) Energy Efficiency/de-carbonisation measures on the demand side
  (iii) Production and distribution of coal
  (iv) Electricity generation, transmission and distribution
  (v) Augmenting supply of oil and gas, both by domestic E&P, and through
  acquisition of overseas acreages
  (vi) Refining and distribution of oil and gas.
  (vii) Installation, generation and distribution of renewable energy

# 3. ENERGY MANAGEMENT AND AUDIT

**Syllabus**
**Energy Management & Audit:** Definition, Energy audit- need, Types of energy audit, Energy management (audit) approach-understanding energy costs, Bench marking, Energy performance, Matching energy use to requirement, Maximizing system efficiencies, Optimizing the input energy requirements, Fuel and energy substitution, Energy audit instruments

## 3.1 Definition & Objectives of Energy Management

The fundamental goal of energy management is to produce goods and provide services with the least cost and least environmental effect.

The term energy management means many things to many people. One definition of energy management is:

*"The judicious and effective use of energy to maximize profits (minimize costs) and enhance competitive positions"*

(Cape Hart, Turner and Kennedy, Guide to Energy Management Fairmont press inc. 1997)

Another comprehensive definition is

"The strategy of adjusting and optimizing energy, using systems and procedures so as to reduce energy requirements per unit of output while holding constant or reducing total costs of producing the output from these systems"

The objective of Energy Management is to achieve and maintain optimum energy procurement and utilisation, throughout the organization and:

- To minimise energy costs / waste without affecting production & quality
- To minimise environmental effects.

## 3.2 Energy Audit: Types And Methodology

Energy Audit is the key to a systematic approach for decision-making in the area of energy management. It attempts to balance the total energy inputs with its use, and serves to identify all the energy streams in a facility. It quantifies energy usage according to its discrete functions. Industrial energy audit is an effective tool in defining and pursuing comprehensive energy management programme.

As per the Energy Conservation Act, 2001, Energy Audit is defined as "the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption".

### 3.2.1 Need for Energy Audit

In any industry, the three top operating expenses are often found to be energy (both electrical and thermal), labour and materials. If one were to relate to the manageability of the cost or potential cost savings in each of the above components, energy would invariably emerge as a top ranker, and thus energy management function constitutes a strategic area for cost reduction. Energy Audit will help to understand more about the ways energy and fuel are used in any industry, and help in identifying the areas where waste can occur and where scope for improvement exists.

The Energy Audit would give a positive orientation to the energy cost reduction, preventive maintenance and quality control programmes which are vital for production and utility activities. Such an audit programme will help to keep focus on variations which occur in the energy costs, availability and reliability of supply of energy, decide on appropriate energy mix, identify energy conservation technologies, retrofit for energy conservation equipment etc.

In general, Energy Audit is the translation of conservation ideas into realities, by lending technically feasible solutions with economic and other organizational considerations within a specified time frame.

The primary objective of Energy Audit is to determine ways to reduce energy consumption per unit of product output or to lower operating costs. Energy Audit provides a " bench-mark" (Reference point) for managing energy in the organization and also provides the basis for planning a more effective use of energy throughout the organization.

### 3.2.2 Type of Energy Audit

The type of Energy Audit to be performed depends on:

- Function and type of industry
- Depth to which final audit is needed, and
- Potential and magnitude of cost reduction desired

Thus Energy Audit can be classified into the following two types.

i) Preliminary Audit
ii) Detailed Audit

### 3.2.3 Preliminary Energy Audit Methodology

Preliminary energy audit is a relatively quick exercise to:

- Establish energy consumption in the organization
- Estimate the scope for saving
- Identify the most likely (and the easiest areas for attention
- Identify immediate (especially no-/low-cost) improvements/ savings
- Set a 'reference point'
- Identify areas for more detailed study/measurement
- Preliminary energy audit uses existing, or easily obtained data

### 3.2.4 Detailed Energy Audit Methodology

A comprehensive audit provides a detailed energy project implementation plan for a facility, since it evaluates all major energy using systems.

This type of audit offers the most accurate estimate of energy savings and cost. It considers the interactive effects of all projects, accounts for the energy use of all major equipment, and includes detailed energy cost saving calculations and project cost.

In a comprehensive audit, one of the key elements is the energy balance. This is based on an inventory of energy using systems, assumptions of current operating conditions and calculations of energy use. This estimated use is then compared to utility bill charges.

Detailed energy auditing is carried out in three phases: Phase I, II and III.

Phase I - Pre Audit Phase
Phase II - Audit Phase
Phase III - Post Audit Phase

### A Guide for Conducting Energy Audit at a Glance

Industry-to-industry, the methodology of Energy Audits needs to be flexible.

A comprehensive ten-step methodology for conduct of Energy Audit at field level is presented below. Energy Manager and Energy Auditor may follow these steps to start with and add/change as per their needs and industry types.

**Ten Steps Methodology for Detailed Energy Audit**

| Step No | PLAN OF ACTION | PURPOSE / RESULTS |
|---|---|---|
| | Phase I –Pre Audit Phase | |
| Step 1 | • Plan and organise<br>• Walk through Audit<br>• Informal Interview with Energy Manager, Production / Plant Manager | • Resource planning, Establish/organize a Energy audit team<br>• Organize Instruments & time frame<br>• Macro Data collection (suitable to type of industry.)<br>• Familiarization of process/plant activities<br>• First hand observation & Assessment of current level operation and practices |
| Step 2 | • Conduct of brief meeting / awareness programme with all divisional heads and persons concerned (2-3 hrs.) | • Building up cooperation<br>• Issue questionnaire for each department<br>• Orientation, awareness creation |
| | Phase II –Audit Phase | |
| Step 3 | • Primary data gathering, Process Flow Diagram, & Energy Utility Diagram | • Historic data analysis, Baseline data collection<br>• Prepare process flow charts<br>• All service utilities system diagram (Example: Single line power distribution diagram, water, compressed air & steam distribution.<br>• Design, operating data and schedule of operation<br>• Annual Energy Bill and energy consumption pattern (Refer manual, log sheet, name plate, interview) |
| Step 4 | • Conduct survey and monitoring | • Measurements :<br>Motor survey, Insulation, and Lighting survey with portable instruments for collection of more and accurate data. Confirm and compare operating data with design data. |
| Step 5 | • Conduct of detailed trials /experiments for selected energy guzzlers | • Trials/Experiments:<br>- 24 hours power monitoring (MD, PF, kWh etc.).<br>- Load variations trends in pumps, fan compressors etc. |

| | | |
|---|---|---|
| | | - Boiler/Efficiency trials for (4 – 8 hours)<br>- Furnace Efficiency trials<br>Equipments Performance experiments etc |
| Step6 | • Analysis of energy use | • Energy and Material balance & energy loss/waste analysis |
| Step 7 | • Identification and development of Energy Conservation (ENCON) opportunities | • Identification & Consolidation ENCON measures<br>• Conceive, develop, and refine ideas<br>• Review the previous ideas suggested by unit personal<br>• Review the previous ideas suggested by energy audit if any<br>• Use brainstorming and value analysis techniques<br>• Contact vendors for new/efficient technology |
| Step 8 | • Cost benefit analysis | • Assess technical feasibility, economic viability and prioritization of ENCON options for implementation<br>• Select the most promising projects<br>• Prioritise by low, medium, long term measures |
| Step9 | • Reporting & Presentation to the Top Management | • Documentation, Report Presentation to the top Management. |
| | <u>Phase III –Post Audit phase</u> | |
| Step10 | • Implementation and Follow-up | Assist and Implement ENCON recommendation measures and Monitor the performance<br>• Action plan, Schedule for implementation<br>• Follow-up and periodic review |

## Phase I -Pre Audit Phase Activities

A structured methodology to carry out an energy audit is necessary for efficient working. An initial study of the site should always be carried out, as the planning of the procedures necessary for an audit is most important.

### Initial Site Visit and Preparation Required for Detailed Auditing

An initial site visit may take one day and gives the Energy Auditor/Engineer an opportunity to meet the personnel concerned, to familiarize him with the site and to assess the procedures necessary to carry out the energy audit.

During the initial site visit the Energy Auditor/Engineer should carry out the following actions: -

- Discuss with the site's senior management the aims of the energy audit.
- Discuss economic guidelines associated with the recommendations of the audit.
- Analyse the major energy consumption data with the relevant personnel.
- Obtain site drawings where available - building layout, steam distribution, compressed air distribution, electricity distribution etc.
- Tour the site accompanied by engineering/production

### The main aims of this visit are: -

- To finalise Energy Audit team
- To identify the main energy consuming areas/plant items to be surveyed during the audit.
- To identify any existing instrumentation/ additional metering required.
- To decide whether any meters will have to be installed prior to the audit eg. kWh, steam, oil or gas meters.
- To identify the instrumentation required for carrying out the audit.
- To plan with time frame
- To collect macro data on plant energy resources, major energy consuming centers
- To create awareness through meetings/ programme

## Phase II- Detailed Energy Audit Activities

Depending on the nature and complexity of the site, a comprehensive audit can take from several weeks to several months to complete. Detailed studies to establish, and investigate, energy and material balances for specific plant departments or items of process equipment are carried out. Whenever possible, checks of plant operations are carried out over extended periods of time, at nights and at weekends as well as during normal daytime working hours, to ensure that nothing is overlooked.

The audit report will include a description of energy inputs and product outputs by major department or by major processing function, and will evaluate the efficiency of each step of the manufacturing process. Means of improving these efficiencies will be listed, and at least a preliminary assessment of the cost of the improvements will be made to indicate the expected payback on any capital investment needed. The audit report should conclude with specific recommendations for detailed engineering studies and feasibility analyses, which must then be performed to justify the implementation of those conservation measures that require investments.

**The information to be collected during the detailed audit includes: -**

1. Energy consumption by type of energy, by department, by major items of process equip ment, by end-use
2. Material balance data (raw materials, intermediate and final products, recycled materials, use of scrap or waste products, production of by-products for re-use in other industries, etc.)
3. Energy cost and tariff data
4. Process and material flow diagrams
5. Generation and distribution of site services (eg.compressed air, steam).
6. Sources of energy supply (e.g. electricity from the grid or self-generation)
7. Potential for fuel substitution, process modifications, and the use of co-generation systems (combined heat and power generation).
8. Energy Management procedures and energy awareness training programs within the establishment.

Existing baseline information and reports are useful to get consumption pattern, production cost and productivity levels in terms of product per raw material inputs. The audit team should collect the following baseline data:

- Technology, processes used and equipment details
- Capacity utilisation
- Amount & type of input materials used
- Water consumption
- Fuel Consumption
- Electrical energy consumption
- Steam consumption
- Other inputs such as compressed air, cooling water etc
- Quantity & type of wastes generated
- Percentage rejection / reprocessing
- Efficiencies / yield

**DATA COLLECTION HINTS**

It is important to plan additional data gathering carefully. Here are some basic tips to avoid wasting time and effort:

- measurement systems should be easy to use and provide the information to the accuracy that is needed, not the accuracy that is technically possible
- measurement equipment can be inexpensive (flow rates using a bucket and stopwatch)
- the quality of the data must be such that the correct conclusions are drawn (what grade of prod uct is on, is the production normal etc)
- define how frequent data collection should be to account for process variations.
- measurement exercises over abnormal workload periods (such as startup and shutdowns)
- design values can be taken where measurements are difficult (cooling water through heat exchang er)

***DO NOT ESTIMATE WHEN YOU CAN CALCULATE***
***DO NOT CALCULATE WHEN YOU CAN MEASURE***

## 2. Energy data management

### 2.1 Energy data analysis

Energy management describes the process of managing the generation and the consumption of energy, generally to minimize demand, costs, and pollutant emissions. The energy management has to look for efficient solutions for the challenges of the changing conditions of the international energy economy which are caused by the world wide liberalization of the energy market restricted by limited resources and increasing prices (Doty & Turner, 2009). Computer aided energy management combines applications from mathematics and informatics to optimize the energy generation and consumption process. Information systems represent the basis for controlling and decision activities. Because of the large number of relevant information an efficient data management is to be used. Therefore mathematical analyzing and optimizing methods are to be combined with energy data bases and with the data management of the energy generation process. The detailed analysis of the main input and output data of an energy system is necessary to improve its efficiency. Improving the efficiency of energy systems or developing cleaner and efficient energy systems will slow down the energy demand growth, make deep cut in fossil fuel use and reduce the pollutant emissions.

Much of the energy generated today is produced by large-scale, centralized power plants using fossil fuels (coal, oil, and gas), hydropower or nuclear power, with energy being transmitted and distributed over long distances to the consumers. The efficiency of conventional centralized power systems is generally low in comparison with combined heat and power (CHP) technologies (cogeneration) which produce electricity or mechanical power and recover waste heat for process use. CHP systems can deliver energy with efficiencies exceeding 90%, while significantly reducing the emissions of greenhouse gases and other pollutants (Petchers, 2003). Selecting a CHP technology for a specific application depends on many factors, including the amount of power needed, the duty cycle, space constraints, thermal needs, emission regulations, fuel availability, utility prices and interconnection issues. The tasks and objectives of a local energy provider can be summarized as follows:

- Supply of the power and heat demand of the delivery district (additionally supply of cool and other media as gas and water is possible)
- Logistic management and provision of the primary fuels and of the support materials; dispose of the waste materials
- Portfolio management (i.e. buying and selling power at the power stock exchange)
- Customer relationship management
- Power plant and grid operation

Fig. 1 shows the relationship model of the main input data resources and the data flow of the energy data management. The energy database represents the heart of the energy information system. The energy data management provides information for the energy controlling including all activities of planning, operating, and supervising the generation and distribution process. A detailed knowledge of the energy demand in the delivery district is necessary to improve the efficiency of the power plant and to realize optimization potentials of the energy system.

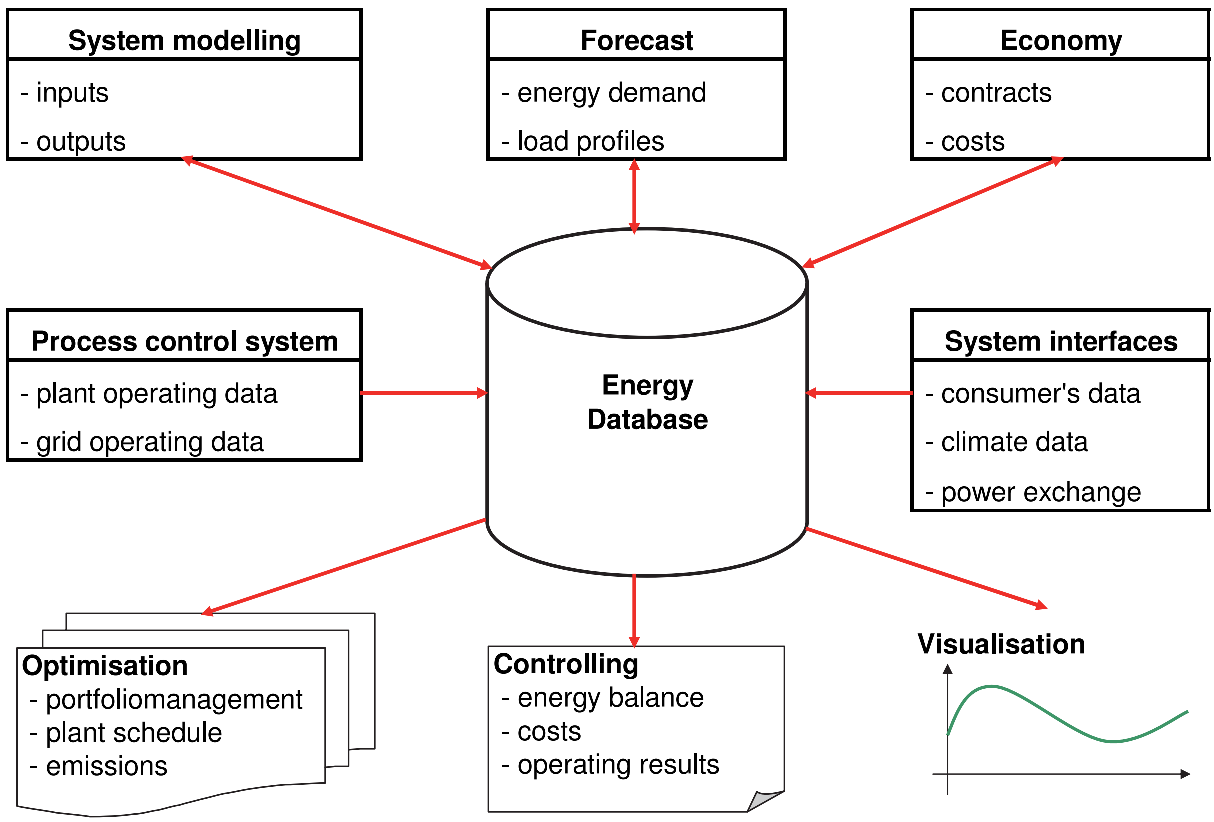



Fig. 1. Energy data management

### 2.2 Mathematical modeling

With the help of an energy data analysis the relations between the main inputs and outputs of the energy system will be described by mathematical models. The process of the mathematical modeling is characterized by the following properties:

- A mathematical model represents the mapping of a real technical, economical or natural system.
- As in real systems generally many influence parameters are determining, the modeling process must condense and integrate them (section 3.1).
- The mathematical modeling combines abstraction and simplification.
- In the most cases the model is oriented to application, i.e., the model is built up for a special use.

The demands for the modeling process can be summarized to the thesis: The model should be exact as necessary and simple as possible. A wide range of statistical modeling algorithms is used in the energy sector. They can be classified according to these three criteria:

- type of the model function (linear / non-linear)
- number of the influence variables (univariate / multivariate)
- general modeling aspect (parametric / non-parametric)

The separation between linear and non-linear methods depends on the functional relationship. A model is called univariate if only one influence factor will be regarded; otherwise it is of the multivariate type. Parametric models contain parameters besides the

input and output variables. The best known linear univariate parametric model is the classical single linear regression model (section 3.4). Non-parametric models as artificial neural networks (section 3.5) don't use an explicit model function.
An explicit algebraic relationship between input and output can be described by the model

$$y = F(x, p) \tag{1}$$

where the function F describes the influence of the input vector x on the output variable y. The function F and the parameter vector p determine the type of the model. Regarding (1) there are two typically used modeling tasks:

**Simulation:**

Calculate the outputs y for given inputs x and fixed parameters p, and compare the results.

**Parameter estimation** (inverse problem):

For given measurements of the input x and the output y calculate the parameters p so that the model fits the relation between x and y in a "best" way.
The numerical calculation of the parameters of the regression model described in section 3.4 represents a typical parameter estimation problem.

### 2.3 Energy demand analysis

The energy consumption of the delivery district of a power plant depends on many different influence factors (fig. 2). Generally the energy demand is influenced by seasonal data, climate parameters, and economical boundary conditions. The heat demand of a district heating system depends strongly on the outside temperature but also on additional climate factors as wind speed, global radiation and humidity. On the other side seasonal factors influence the energy consumption. Usually the power and heat demand is higher on working days than at the weekend. Furthermore vacation and holidays have a significant impact on the energy consumption. Last but not least the heat and power demand in the delivery district is influenced by the operational parameters of enterprises with large energy demand and by the consumer's behavior. Additionally the power and heat demand follow a daily cycle with low periods during the night hours and with peaks at different hours of the day.
The quality of the energy demand forecast depends significantly on the availability of historical consumption data and on the knowledge about the main influence parameters on the energy demand. The functional relationship is non-linear and there are more or less complex interactions between different data types. Because of the large number of influence factors and their uncertainty it is impossible to build up an 'exact' physical model for the energy demand. Therefore the energy demand is calculated on the basis of mathematical models simplifying the real relationships as described in the previous section. Since no simple deterministic laws that relate the predictor variables (seasonal data, meteorological data and economic factors) on one side and energy demand as the target variable on the other side exist, it is necessary to use statistical models. A statistical model learns a quantitative relationship from historical data. During this training process quantitative relationships between the target variables (variables that have to be predicted) and the predictor variables are determined from historical data. Training data sets must be provided for known predictor target variables. From these example data the mathematical model is determined. This model can then be used to compute the values of the target variables as a function of the predictor variables for periods for which only the predictor variables are

known. Using meteorological data as predictor variables forecasts for those meteorological variables are needed (Fischer, 2008).

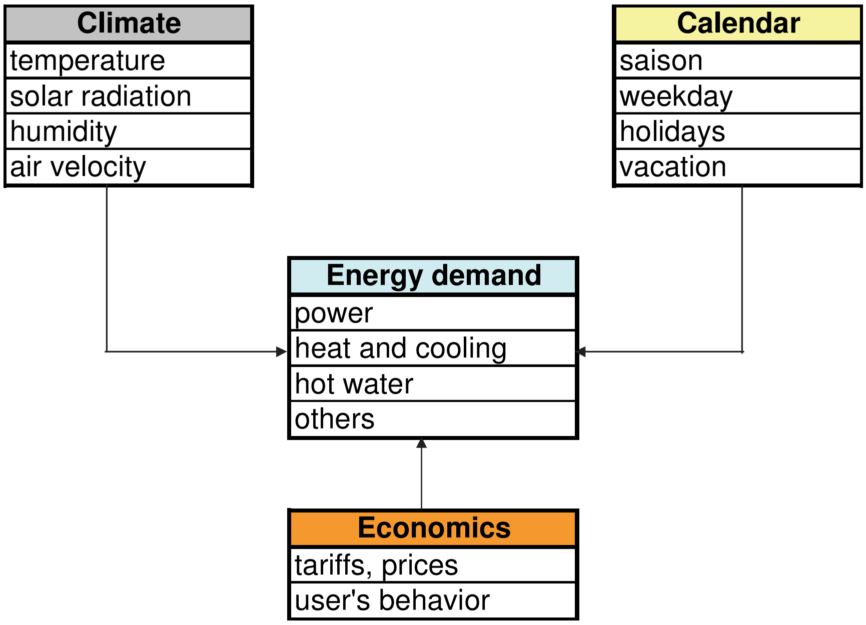



Fig. 2. Relationship model of the energy demand

The analysis of the relationships between energy consumption and climate factors includes the following activities:

- energy balancing (distribution of the demand)
- analysis of the main influence factors (fig. 2)
- design of the mathematical model
- analysis and modeling of typical demand profiles

The daily cycle of the power and heat consumption can be described by time series methods (see 3.3). For non-interval metered customers "Standard load profiles" (SLP) can be used. They describe the time dependent load of special customer groups, e.g. residential buildings, small manufactories, office buildings, etc. (VDEW, 1999).

### 2.4 Energy controlling and optimization

The power generation system of the provider generally consists of several power plants including distributed units as cogeneration systems, wind turbines, and others (fig. 3). The provider is faced with the task to find the optimal combination (schedule) of the different generation units to satisfy the power and heat demand of the customers. Because of the unbundled structure of the generation, distribution and selling of electricity a lot of technical relations and economical conditions are to be modeled.

As the architecture of the future electricity systems can be characterized by a combination of conventional centralized power plants with an increasing number of distributed energy resources, the generation scheduling optimization becomes more and more important. The schedule selects the operating units and calculates the amount to generate at each online unit in order to achieve the minimum production cost. This generation scheduling problem requires determining the on/off schedules of the plant units over a particular time horizon. Apart from determining the on/off states, this problem also involves deciding the hourly

# Energy Pricing

Prem Kalra

This paper attempts to address issues, myths, and realities about transmission pricing in the Indian context. Electric power transmission forms an important link between electricity generators and consumers. The transmission network is used for electricity trading, providing open access, and transfer of electricity. The Electricity Act, 2003, permits open access, which essentially means that the consumer can purchase power from anywhere, the only constraint being the availability of transmission capacity. Available transmission capacity can be determined under static as well as dynamic operating conditions.

In India, availability-based tariff (ABT), which is already in place, governs the charges for unscheduled interchange as well as frequency-dependent rewards and penalty mechanisms. Similarly, reactive power pricing has been indirectly incorporated by charging for the voltage drop/rise in access to the threshold. These mechanisms mark the beginnings in creating grid discipline and must be carried forward to promote capacity expansion. The Central Electricity Regulatory Commission (CERC) and the N. K. Singh Committee have already deliberated on the pricing mechanisms and their suitability in the Indian context. But they did not touch upon other issues influencing transmission pricing policy. Some of these are: auxiliary services; quality of power; quality of services; congestion; energy efficiency; and energy conservation.

A good pricing mechanism must lead to optimum usage and expansion of capacity. It must be simple to use and understand. As a first step, CERC has done a creditable job by coming up with a block-based postage stamp method, but this needs to be carried forward to accommodate other factors like weather variation and the time of the day.

A major bottleneck in supporting any decision on transmission pricing is nonavailability of both technical and financial data. Also, a long-term investment policy for generation and transmission is required for financial supporters to compute the returns on investment. A web-based database would facilitate, for any investor, formulation of a business plan based on ballpark figures concerning the cost of fuel, generation and transmission, losses in transmission, and possible congestion in the transmission network.

Investors in generation primarily need information concerning transmission pricing from a given generation location to the assumed locations of consumers. This requires a chart that indicates the transmission pricing at different locations from all possible locations of generation. This task is not easy, but it needs to be done urgently to attract investment in generation. Alongside, transmission margins also need to be computed under different operating conditions.

To facilitate comparison between different pricing methods, the pricing should cover all energy transmission charges, including infrastructure charges (operation and capital), loss compensation costs, internal congestion costs (but no costs of auctions or market splitting), costs of supply of system services, and stranded costs.

The Electricity Act, 2003, encourages independent power producers, generation based on renewables, and distributed generation. Most types of renewable generation experience problems, such as an increase in transmission cost due to limited flexibility in choosing the location of a facility, greater distance from the load, coincidence with the peak load, low capacity factor, and intermittence. If the Government of India wants to promote renewable, distributed generation, and other sources of electricity generation, it must provide some kind of subsidies in transmission pricing. These subsidies can be recovered by reducing losses and improving the operating conditions of the transmission network. The obvious advantage in promoting and financing renewables-based generation and distributed generation is the shorter time constant involved.

Broadly speaking, transmission pricing must cover:

- *Connection charge*. This will cover the cost of network reinforcements required to provide service to a transmission customer.
- *Transmission use-of-system charge (capacity charge)*. This will compensate the transmission owner for the sunk costs of the

existing transmission system assets, as well as for the transmission system operating and maintenance costs.

- *Transmission operating charge (energy charge)*. This will cover the costs incurred in the electricity market due to the existence of a 'nonperfect' transmission system. This includes the costs of transmission losses and transmission limitations (congestion). The revenues collected from energy charges are used to compensate the providers of the corresponding services (generation adjustment to cover losses, and generation or demand adjustment to relieve congestion). In the Indian context, load can be treated as negative generation. This means that if a lower pricing load is brought in to replace a higher pricing load to meet the existing generation, a loss of revenue will result. This loss would become the congestion cost.

No transmission pricing method addresses all issues. It has, hence, been suggested that methodologies be designed for pricing relevant to the particular country. In India, investments are needed in all kinds of generation schemes, in transmission capacity expansion in different regions, and in cleaning up electricity distribution. It is important, therefore, that in transmission pricing the cost to the generator and distributor should not be heavily loaded.

The pricing principles used by a regulated company must maximize investment and operational efficiencies. This calls for adequate returns on investment and also for incentives to reduce losses and maximize power transfer capacity. To achieve this, a price cap may be imposed by regulatory bodies, but price caps may discourage small companies from investing in the sector.

Transmission pricing methods should:

- promote efficient day-to-day operation of the bulk power market;
- signal locational advantages for investment in generation and demand;
- signal the need for investment in the transmission system;
- compensate the owners of existing transmission assets; and
- be simple, transparent, and politically executable.

Various constraints like congestion, thermal limits, voltage limits, and stability affect power transmission pricing. Nonstorability of electricity, in combination with transmission capacity constraints, suggests that pricing in the short run is important to avoid congestion. At the same time, since prices guide the operating and investment decisions of transmission companies, generators, and load-serving entities (distribution companies), pricing approaches need to be geared at highly differentiated time horizons.

In some methods, all system costs (existing transmission system, operation, and expansion) are allocated among the system users in proportion to their 'extent of use' of transmission resources. Allocation methodologies differ in their definitions and measure of the 'extent of use'. They can be classified as load-flow-based methods and rolled-in methods. The main shortcoming of the latter methods (such as postage stamp and contract path) is that they ignore actual system operation. As a result, they are likely to send incorrect economic signals to transmission customers. For instance, in the postage stamp method, an agent who uses the system lightly (generation and load at short electrical distance) would be subsidizing another who uses the system heavily. Such cross-subsidies can be identified by analyzing pool stability. An allocation rule is stable if each agent pays *less* as a member of the integrated pool than as a member of any subpool or as an isolated agent.

Including long-term dynamics in transmission cost allocation methods is not easy basically because of the inherent uncertainties over the future configuration of the system, hydrological conditions, and load growth. In a competitive environment this uncertainty increases due to generation investment decisions, posing new challenges to transmission system planners.

The differences among the various proposed schemes for the definition of transmission rights, transmission pricing, and congestion management can be categorized along several dimensions, as follows:

- physical vs. financial transmission rights;
- link-based vs. node-based (point to point) definition of transmission rights;
- access-based vs. usage-based pricing;
- locational differentiation in tariffs: nodes, zones, or uniform prices;
- ex-ante vs. ex-post pricing;
- bundling of transmission service and energy vs. treating energy and transmission service as separate commodities; and
- congestion management through efficient generation dispatch vs. efficient congestion relief.

Some of the difficulties faced in determining the right strategy for computing transmission pricing are:

- Regulatory oversight of electric utility pricing practices, which constrains pricing methods from being cost-based, simple, and stable over 'long' periods.
- Limited experience of the utility industry with the provision of large-scale transmission services.
- Tools and data for evaluating the economic and technical impact on the performance of pricing and transmission services are neither understood nor available at large.
- Transmission planning and influence of generation planning on transmission expansion.

To achieve economic efficiency, congestion charges must be separated from network access charges. Regulators should consider instituting congestion pricing and using an energy-based access charge to recover fixed costs. An energy-based access charge leads to the least-cost mix of generation technologies. Collecting fixed costs through a capacity-based access charge is demonstrably unfair to intermittent renewable generators and results in too little renewable generation compared with the least-cost technology mix.