1. INTRODUCTION (ENERGY USE & ENVIRONMENT)

On the successful completion of this unit you will be able to;

✓ Understanding and identifying the current energy sources and scenario

✓ Understanding the various Renewable and non-renewable sources and characteristic

✓ Know the current performance benchmarking of various energy sectors and devices

✓ Able to design and analysis major energy system

✓ Understand the methods used for energy management in an industries

✓ Identify opportunities of future energy source and potential

1.0 World Energy

• There are 2 billion people who have no access to modern energy resources.

• Energy consumption is increasing at 3% annually.

• High standard of living is closely related to energy use.
• An indication of the energy use trend from 1970 projected to 2025 is given here.

Energy Use Trend from 1970 to 2025

A Sankey diagram is used to describe flows through a system. The thicker the line, the greater the amount involved. It is based on a hundred units at the beginning represented by two parallel lines from the left [en.wikipedia.org/wiki/Sankey_diagram].

Activity 1:
Construct a Sankey diagram for the different sectors in a selected country for 2006. Identify the major sector that uses the most amount of energy in that country.

Click for help (link to Sankey for China.doc)
Relevant data may be obtained [here](link to EConsumption by Sector2005.doc)

Reliance on Fossil Fuels

- Fossil fuels currently meet about 80% of the world energy.
- Hydropower and nuclear each contributes 7% and 5% respectively to the total energy production. The rest comes from renewable energy. Current and projected primary energy source distribution may be obtained [here](link to Energy source ppt).
- Energy consumption varies across the sectors.
- The sum of all the energy consumption by the sectors is called total final energy consumption (TFC).
- There is a need to
  - Conserve fossil fuel resources for the future.
  - Create adequate substitutes in quantities that should meet future requirements.
  - Manage the supplies of energy.

**Activity 2:**
Devise a pie chart and comment on the distribution and trends of energy use for various sectors in a developed/developing/under-developed country.

**SOURCE:**

Environmental Issues

- Concerns about depletion of non-renewable energy resources (ER) started in the late 1960s.
- Today’s energy systems have produced and will continue to produce significant environmental impact.
- Energy conversion and use are the major contributors to anthropogenic greenhouse gas emissions.

**World Carbon dioxide emission by fuel type, 1970 -2025**

- Major environmental issues are
  - **Acid rain**
    - Sulphurous gases emitted by power plants are converted to fine sulphate particles and other acidic species through chemical processes in the atmosphere.
    - The acidic deposition in wet or dry form can cause a variety of effects;
• killing some sensitive living species,
• declining other living species,
• disrupt complex soil chemistry,
• deterioration of building materials, and
• affect human health.

○ **Greenhouse effects**
  - Gases such as CO$_2$, CH$_4$, N$_2$O, and Halocarbons released through human activities have long lifetime in the atmosphere.
  - These gases called the greenhouse gases absorb outgoing energy from the earth and caused a warming effect.
  - CO$_2$ emitted from the combustion of oil, gas, and coal is of major concern.

○ **Depletion of the ozone layer**
  - Chlorofluorocarbons (CFCs) from the refrigeration industry released into the atmosphere deplete the ozone layer that normally protects the earth from the sun’s ultra-violet radiation.
  - These CFCs also caused global warming similar to that from the GHG.

○ **Large area deforestation**
  - Growths of cities and modern suburbs have caused major degradation and loss in ecologically rich habitats, both aquatic and terrestrial.
- Population growth and fragmentation of forested areas into smaller regions have contributed to the decline and loss of species.

The Kyoto Protocol was adopted in 1997 to deal with the greenhouse gases.

- with Clean Development Mechanism (CDM) was established with emissions trading

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**Kyoto Protocol** - The 1997 accord where leaders of industrialized countries agreed to reduce their overall emissions of CO₂, CH₄, and N₂O to an average of 5.2% below 1990 levels by the period 2008 to 2012. Overall emissions of perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and sulphur hexafluoride (SF₆) are to be reduced to 5.2% below 1995 levels.

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**Clean Development Mechanism** -

(i) To assist parties not included in Annex I of the Kyoto Protocol in achieving sustainable development and in contributing to the ultimate objective of the Convention, and

(ii) To assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3.
Emissions trading (or cap and trade) - An administrative approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants. A central authority sets a cap on the amount of a pollutant that can be emitted. Companies or other groups that emit the pollutant are given credit which represents the right to emit a specific amount. The total amount of credits cannot exceed the cap, limiting total emissions to that level. Companies that pollute beyond their allowances must buy credits from those who pollute less than their allowances.

- Stabilizing the amount of greenhouse gases in the atmosphere requires reducing CO$_2$ emissions through the participation of the developing countries.

1.1 Worldwide Energy Resource

- World energy resources are available well into the future generation but the price tag for them may be too high for some.

- Opportunities for research, development, market availability depend very much on both the local government and world policies and implementation.

- A list of world energy sources for 2006 may be obtained [here.](link to EConsumption by Source2005 .doc)

1.2 Sustainable Energy

- Depletion of resources and long-term activities that degrade our environment have generated interest in sustainable energy.
• Energy needs are basically driven by the three principal factors;
  o Population growth
  o Economic and industrial development
  o Technological change

• Sustainable development (according to WCED 1987) is development that meets the present without compromising the ability of future generations to meet their own needs.

• Sustainable developments can be represented by a sustainable energy cycle,

- Unsustainable development is produced when one or more of the three Es is missing,
or one of the flow has been reversed,

- The concept of $E^3$ can be applied to a typical hydropower plant to see if the system satisfies the sustainable development criteria. [Example of hydro...] The system information is available at CompEdu. [Link to CompEdu]
1.3 Environment

- Most emissions standard regulated pollutants from the transport sector. They are NO$_x$, particulate matter (PM) or soot, carbon monoxide (CO), and volatile hydrocarbons (volatile organic compounds or VOCs).
- Non-regulated emitted pollutants include sulphur dioxide (SO$_2$), carbon dioxide (CO$_2$), and water vapor (H$_2$O).
- Pollutants have impact on the global environment. These are:

  - NO$_x$: hacking coughs, kidney disease, effects on pulmonary functions
  - PM (soot): respiratory-related diseases (bronchitis), cardiovascular diseases, damage to lung tissue
  - SO$_2$ + water: breathing difficulties, alterations in the lung’s defences, aggravation of current cardiovascular or chronic lung diseases
  - CO: shortness of breath, dizziness
  - CO$_2$: adverse effects on heart-problem patients

*Animation with the arrows above*

- Advance in technological development of new engine systems have managed to reduce the pollutants through the years,
• The following table shows a decrease in pollutant emissions for the past ten years for the average cars in general.

<table>
<thead>
<tr>
<th>Pollutants emitted in driving 16,000 kilometers (10,000 miles), in kilograms</th>
<th>CO</th>
<th>HC</th>
<th>NOₓ</th>
<th>PM₁₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average 1990 car</td>
<td>295</td>
<td>48</td>
<td>23</td>
<td>5.45</td>
</tr>
<tr>
<td>Average 1998 car</td>
<td>159</td>
<td>17</td>
<td>17</td>
<td>0.33</td>
</tr>
<tr>
<td>Average 1998 pickup/SUV</td>
<td>182</td>
<td>0.1</td>
<td>19</td>
<td>0.06</td>
</tr>
<tr>
<td>2001 Volkswagen Lupo</td>
<td>-</td>
<td>4.5</td>
<td>2.8</td>
<td>0.26</td>
</tr>
</tbody>
</table>

PM₁₀ is for particles of size under 10 μm.

A person who has bought a car in 1990 which has by now clocked 350,000 kilometers would have released

\[ 350,000 \text{ km} \times \frac{295 \cdot \text{kg} \cdot \text{CO}}{16,000 \cdot \text{km}} = 6,453 \text{ kg of CO} \]

• In the developing and developed countries of today, almost every household in the city owns a minimum of two vehicles.

• Imagine a household of adult professionals who insist on using their own car to move around the city!!

Activity 4:
If you own a 1998 SUV and your wife drives a 2001 Volkswagen Lupo, how much CO, HC, NOₓ, and PM₁₀ have both of you contributed to the environment up to 2005? Assume that you drive around the country about 25,000 kilometers annually while your wife’s daily use comes to about 2,400 kilometer per year.
• All pollutants are harmful to everyone, more so to some than others.

• GHG are distinguished from other pollutants by their long lifetime in the atmosphere. [Human-induced CO₂ levels in the atmosphere cannot be easily reversed. Some degree of future warming is inevitable]

• Emissions and changing weather conditions (the El-Nino) can produce severe impacts on the population at large (Butterfly effect)

**Activity 5:**
Comment on the socioeconomist Garrett Hardin’s “tragedy of the commons” against economist Adam Smith’s argument that an individual intent on personal gain would be led to benefit the public interest by an “invisible hand” in relation to the harmful pollutants that are emitted by megacities.

• To get an idea of the amount of pollutants emitted by a particular energy source in use, a simple model calculation of CO₂ emissions from 1 tonne of oil, coal or gas is given by Paul O’Callaghan:

<table>
<thead>
<tr>
<th>Fuel type/Amount</th>
<th>CO₂ released (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil (C₇H₁₆ – C₁₀H₂₂) – 1 tonne</td>
<td>3142.8</td>
</tr>
<tr>
<td>Coal (C₁₃₅H₉₆O₉NS) – 1 tonne</td>
<td>3616.4</td>
</tr>
<tr>
<td>Gas (CH₄) – 1 m³</td>
<td>2.2</td>
</tr>
</tbody>
</table>
where 1 toe coal is equivalent to 1.579 tonnes of coal (C₆H) and 1 toe of gas is equivalent to 0.946 tonnes of gas or 1182.29 m³ of gas.

- Malaysia’s consumption of 4% of 51,608 metric toe of coal in year 2005, the amount of CO₂ produced is expected to be

$$0.04 \times 51,608 \text{ toe} \times \frac{1.579 \text{ tonnes}}{\text{toe}} \times 3616.4 \text{ kg CO}_2 \text{ tonne}$$

$$= 11.8 \times 10^6 \text{ kg of CO}_2 \text{ released}$$

$$= 11.8 \times 10^6 \text{ kg} \times 1.78 \frac{m^3}{kg} = 21 \times 10^6 \text{ m}^3 \text{ of CO}_2 \text{ at } 30^\circ\text{C}$$

This is equivalent to five size of Wembley Stadium

**Activity 6:**

Compare the amount of CO₂ emitted from the (i) transport, (ii) residential, (iii) industrial sector in your country against that of another country from another continent of a similar magnitude in population.

- An estimated 4.6 million deaths each year is attributed to air pollution.

- An index called the Global Warming Potential (GWP) is used to estimate the CO₂ equivalence of different gases.

**Activity 7:**

Supply evidence that one particular country in the G-8 group had CO₂ emissions more than 50% of the total emissions from the G-8 group.
1.4 Economics

- The cost of a particular project or technology alone cannot address environmental issues associated with that project/technology.

- A cost-benefit analysis (CBA) compares the economic benefits of an activity to the total cost of the undertaking.

- A merit results when benefits exceed the cost.

- The following is a CBA example

Example
The cost of reducing toxic discharges to rivers and lakes is estimated at $100 million in Year 1, $150 million in Year 2, and $100 million in Year 3. The economic benefits from this exercise are estimated at $50 million/year for each of the next 12 years. Perform a cost-benefit analysis for this proposal. You may assume a real discount rate of 6%/year, with all costs and benefits occurring at the end of each year.

A cash flow diagram for the analysis above is

Click here for answer (link to Solution.doc)
Supply/Demand/Mix

- Electricity is the fastest growing form of energy worldwide.
- Developing countries like China and India are using double the electricity in 2000 compared to 1990.
- Energy consumption per capita, energy reserves and imports worldwide may be viewed [here. (link to EResrvs 2005.doc)]
- Imports and exports of fuel (oil, coal and natural gas) by countries are given [here. (link to EimporExport 2005.pdf)]

Energy Costs

- Energy prices are more expensive now compared to the 1950s, 1960s, and the late 1980s. [Click for graph] (link to Oil Prices 1861-2006.jpeg)
- Demand for energy has not decreased or showing any sign of slowing down.
2.0 CHARACTERISTICS OF ENERGY SOURCES

2.1 Non-Renewable

- Non-renewable energy refers to the energy resources that occur naturally but depleted with time as they are mined and utilized to meet the ever increase in global energy demands.

- Types of non-renewable energy sources are derived from gas, liquid or solid fossil fuel such as diesel, gasoline, heating oil, distillate coal and natural gas.

**Fossil Fuel**

- A fossil fuel can either be a solid, liquid, or gaseous fuel material.

- Fossil fuels consist mainly of carbon and hydrogen; the proportion of carbon is largest in coal and smallest in natural gas.

- Carbon and hydrogen (and their compounds) can burn in air;

\[ C_aH_b + (a+b/4)(O_2+3.773N_2) \Rightarrow aCO_2 + (b/2)H_2O + 3.773 (a+b/4) N_2 \]

Note: a and b are number of atoms for carbon and hydrogen in the fuel respectively.
A fossil fuel is formed in the ground by chemical and physical changes in plant (mainly) and animal residues under high temperature and pressure over geological time periods. The major fossil fuels are coal, petroleum, and natural gas. Petroleum products, such as fuel oils, are often included among the fossil fuel. Peat is thought to be an intermediate stage in the formation of most coals.

- Oil shale contains combustible material derived from fossilized plant residues; the oil obtained by heating the shale is generally regarded as a synthetic fuel (or synfuel) rather than a fossil fuel.

**Diesel Fuel**

- Diesel fuels are either various distillates obtained in petroleum refining operations or blends of such distillates with residual oil.

- An important criterion of diesel fuel is the ignition quality as indicated by the cetane number.

- The American Society for Testing and Materials (ASTM) distinguishes three main grades of diesel fuel as i) Grade 1-D (volatile light distillate, for engine that require frequent speed and load change), ii) Grade 2-D (medium distillate, industrial and heavy mobile service engines) and iii) Grade 4-D (higher heavy distillate, large but slow speed engines).

**Activity 8:**
State and discuss the important criterion of diesel fuel and the different grades?
Gasoline

- The liquid most widely used as fuel for internal combustion engines with electric spark ignition.

- It consists of a mixture of hydrocarbons usually containing 5 to 12 carbon atoms per molecule and boiling almost entirely in the temperature range of about 32 to 205°C.

- Commercial gasolines are blend of petroleum refinery products which provide the characteristics required for different engines under various conditions.

- The main source of main hydrocarbons, and their antiknock properties are displayed below;
Two important characteristics of gasoline are volatility and antiknock properties.

**Fuel Oil**

- Fuel or heating oil is classified by the American Society for Testing of Materials (ASTM) divides fuel oils into the following six categories, based on the type of burner for which the oil is suitable.

  - **No. 1 Heating Oil** – a light distillate of relatively high volatility and low viscosity.
  - **No. 2 Heating Oil** - a medium distillate.
  - **No. 4 Fuel Oil** - either a heavy distillate or a light residual oil.
  - **No. 5 Fuel Oil (Light)** - a medium residual oil, somewhat more viscous than No. 4 Fuel Oil.

<table>
<thead>
<tr>
<th>Source</th>
<th>Main hydrocarbon</th>
<th>Antiknock properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gasoline</td>
<td>Normal paraffins</td>
<td>Poor</td>
</tr>
<tr>
<td>Straight-run</td>
<td>Normal paraffins</td>
<td>Poor</td>
</tr>
<tr>
<td>Cracking (catalytic)</td>
<td>Isoparaffins and aromatics</td>
<td>Good</td>
</tr>
<tr>
<td>Hydrocracking</td>
<td>Isoparaffins and aromatics</td>
<td>Good</td>
</tr>
<tr>
<td>Reforming</td>
<td>Aromatics</td>
<td>Good</td>
</tr>
<tr>
<td>Alkylation</td>
<td>Isoparaffins</td>
<td>Good</td>
</tr>
<tr>
<td>Isomerization</td>
<td>Isoparaffins</td>
<td>Good</td>
</tr>
</tbody>
</table>
- **No. 5 Fuel Oil (Heavy).** - a medium residual oil more viscous than No.5 Fuel Oil (Light).
- **No. 6 Fuel Oil.** - a high-viscosity, heavy residual oil.

- The heating value of a fuel oil (per unit mass) generally decreases from about 46.5 MJ/kg for the lightest oil to roughly 43.7 MJ/kg for the heaviest.

**Activity 9:**
Identify at least 1 application for each type of fuel category mentioned above.

**Distillate**

- The term distillate is usually applied to liquids boiling at temperatures higher than about 180°C, which is above most of the gasoline range.
- Petroleum distillates are commonly classified as light, medium (middle or intermediate), and heavy.

*Synfuels* can be made from coal (coal gasification; coal liquefaction), petroleum products (High-Btu fuel gas), oil shale, tar sands, or plant products (biomass fuels). Among the *synfuels* are various fuel gases, including but not restricted to substitute natural gas, liquid fuels for engines (e.g. gasoline, diesel fuel, and alcohol fuels) and burner fuels (e.g. fuel (heating) oil).

**Coal**

- Coal is a complex mixture of organic chemical substances containing carbon, hydrogen and oxygen in chemical combination, together with smaller amounts of nitrogen and sulphur.
• Coalification is the name given to the development of the series of substances known as peat, lignite or brown coal, sub-bituminous coal, bituminous coal, and anthracite.

![Coal](image)

**Coal**

• The “rank” of a coal indicates the degree of coalification. The ranking for coal is as follows;

<table>
<thead>
<tr>
<th>Rank</th>
<th>(Weight %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carbon</td>
</tr>
<tr>
<td>Anthracite</td>
<td>75-85</td>
</tr>
<tr>
<td>Bituminous</td>
<td>65-80</td>
</tr>
<tr>
<td>Subbituminous</td>
<td>57-69</td>
</tr>
<tr>
<td>Lignite</td>
<td>35-45</td>
</tr>
</tbody>
</table>
The rank assigned to a particular coal is determined largely by the fixed (or nonvolatile) carbon content and the heating value.

Typical (“proximate”) analyses, for the proportions of moisture, volatile matter (at a temperature of 950°C), fixed carbon, and mineral matter (ash) of “as-received” coal.

The “ultimate” analysis gives the proportions of five important elements in coal, namely, carbon, hydrogen, oxygen, nitrogen, and sulphur.

An important characteristic of certain coals is the tendency for small pieces to soften and adhere (or aggregate) upon heating – caking.

**Activity 10:**
State the differences between LHV and HHV for coal. Identify types of coal that cakes and methods to reduce caking. Fill out the missing values in the following table:

### Composition and Heating Value of coals

<table>
<thead>
<tr>
<th>Rank</th>
<th>Composition (weight %)</th>
<th>Heating Value (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moisture</td>
<td>Volatile matter</td>
</tr>
<tr>
<td>Anthracite</td>
<td>4-12</td>
<td>4-15</td>
</tr>
<tr>
<td>Bituminous</td>
<td>2-15</td>
<td>15-45</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-bituminous</td>
<td>10-25</td>
<td>31-55</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lignite</td>
<td>35-45</td>
<td>22-32</td>
</tr>
</tbody>
</table>
Natural Gas

- Natural gas consists mainly of a mixture of simple paraffin hydrocarbons, of which methane (CH₄) is by far the major constituent (generally 70 to 90 volume percent).
- The gas is found entrapped in the earth's crust at varying depths beneath impervious strata, such as limestone, and may or may not be in association with oil. The gas is drawn from wells, similar to oil wells, and is usually transported by pipelines, sometimes a thousand kilometres or more.
- It is used primarily for heat, in industrial, commercial and residential settings. In many homes it is used for heating and cooking and drying of cloths. It is also used to produce electricity, in many cases using gas fired turbines that are similar to jet engines.
- Gas has the great advantage of producing no smoke or ash on burning, although it is usually much more expensive than coal as a fuel.
• The other constituents are ethane \((C_2H_6)\), propane \((C_3H_8)\), butanes \((C_4H_{10})\), and some higher paraffins.

• Crude natural gas, as it is obtained from a gas well, may be categorized as “dry” or “wet” gas.

• Dry gas consists mainly of methane and ethane; only very small amounts of higher paraffin hydrocarbons.

• Wet gas contains substantial amounts of the higher hydrocarbons that can be condensed to form what are called natural gas liquids.

**Hydroelectric Power (Hydropower)**

• The energy utilized in the generation of hydropower is actually a form of solar energy.
Nuclear Energy

- Energy is released as a result of interactions involving atomic nuclei, that is, reactions in which there is a rearrangement of the constituents (i.e., protons and neutrons) of atomic nuclei; it is also called atomic energy.
- The amount of energy releases is related to the decrease in mass by the Einstein equation for the equivalence of mass and energy; this equation is

\[ E = mc^2 \]

Where \( E \) is the energy released, \( m \) is the decrease in mass, and \( c \) is the speed of light. If \( m \) is expressed in kg and \( c \) in m/sec, the energy \( E \) is obtained in Joules (J).
• The nuclear reactions that are likely to prove useful as energy source fall into two general categories: fusion and fission.
  
  o Fusion reactions - the combination (or fusion) of two light nuclei leads to the formation of a heavier nucleus.
  
  o Fission reactions - a heavy nucleus is split into two nuclei of intermediate mass accompanied by a number of neutrons.

Fission: the splitting of large nuclei such as Uranium or Plutonium into smaller pieces with the release of considerable energy (equivalent to a mass lose by Einstein's formula).

For example:

\[
^{235}\text{U}_{92} + ^1\text{n} \rightarrow ^{144}\text{Ba}_{56} + ^{89}\text{Kr}_{36} + ^3\text{n} + \text{E}
\]

Fusion: A possible reaction for a future fusion reactor is the following in which deuterium and tritium are combined to form energy:
\[ ^2\text{H} + ^3\text{H} \rightarrow ^4\text{He} + ^1\text{n} + \text{Energy} \]

Example of a pressurised water nuclear reactor

Nuclear power plant
• The only useful fission reactions are those in which free neutrons cause fission of nuclei of certain isotopes of uranium and plutonium with odd mass numbers;
  o uranium-233,
  o uranium-235, and
  o uranium-239.

• Only uranium-235 occurs in nature; the other two are made artificially.

• An important aspect of fission as an energy source is that it can be a self-sustaining process.

• Although nuclear energy can be released in either fusion or fission reactions, the only nuclear power reactors in existence are based on fission. In a nuclear reactor, the conditions are such that fission energy is released at a controlled rate. The fission energy is converted into heat in the reactor, and this is utilized to raise steam, directly or indirectly. The steam then drives a turbine-generator to produce electricity in the conventional manner.
2.2 Renewable Energy

- Renewable energy refers to energy resources that occur naturally and repeatedly in the environmental and can be harnessed for human benefit.
- Types of renewable energy sources (RES) namely are biomass, hydropower, geothermal, solar, wind, ocean and others.
- Renewable energy in the global energy mix is shown in figure and table below.

Pie chart of world energy consumption
Trends in Energy Use by Source, 1995-2002

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Annual Rate of Growth</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar photovoltaics</td>
<td></td>
<td>30.9</td>
</tr>
<tr>
<td>Wind Power</td>
<td></td>
<td>30.7</td>
</tr>
<tr>
<td>Geothermal Power *</td>
<td></td>
<td>3.1</td>
</tr>
<tr>
<td>Natural Gas</td>
<td></td>
<td>2.4</td>
</tr>
<tr>
<td>Nuclear Power</td>
<td></td>
<td>2.2</td>
</tr>
<tr>
<td>Oil</td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>Coal</td>
<td></td>
<td>0.7</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td></td>
<td>0.5</td>
</tr>
</tbody>
</table>

* Note: Data available through 2000.

Trend in energy use by source

Source:

- Long-term world energy balance based on sustainability;

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>2000</th>
<th>2020</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BTOE</td>
<td>%</td>
<td>BTOE</td>
</tr>
<tr>
<td>Oil</td>
<td>3.7</td>
<td>40</td>
<td>5.0</td>
</tr>
<tr>
<td>Gas</td>
<td>2.1</td>
<td>22</td>
<td>4.0</td>
</tr>
<tr>
<td>Coal+liguie</td>
<td>2.2</td>
<td>24</td>
<td>3.0</td>
</tr>
<tr>
<td>Total fossil</td>
<td>8.0</td>
<td>86</td>
<td>12.0</td>
</tr>
<tr>
<td>Renewables</td>
<td>0.7</td>
<td>7.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.6</td>
<td>6.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Total commercial energy</td>
<td>9.3</td>
<td>100.0</td>
<td>14.0</td>
</tr>
</tbody>
</table>

Long-term World Energy Balance
Ref: P-R. Bauquis, Oil and Gas Journal, 17/2/2003
“BTOE” – BILLION TON OF OIL EQUIVALENT
**Biomass energy**

- Biomass is normally burned directly for heat or power or converted into biofuels.
- Fraction of household energy from biomass for industrialized and developing nations is shown in the figure below.

**Fraction of household energy use from biomass**

- Biofuels are derived from processed materials like straw, forestry waste, and wood chips which are used directly to produce electricity and they are
  - very clean and
  - efficient and
  - come in solid, liquid and gaseous forms.
- Use of biomass offers the potential to greatly reduce greenhouse emissions.
- The solar energy, which is stored in plants and animals, or in the wastes that they produce, is called biomass energy. This energy can be recovered by burning biomass as a fuel.
**Biomass** - The name given all the earth’s living matter. It is the general term for material derived from growing plants or from animal manure. It is a rather simple term for all organic materials that seems from plants, trees, crops and algae. The components of biomass include cellulose, hemicelluloses, lignin, extractives, lipids, proteins, simple sugars, starches, water, HC, ash, and other compounds. Two larger carbohydrate categories that have significant value are cellulose and hemi-cellulose. The lignin fraction consists of non-sugar type molecules. Biomass is wood, plants, animal mass and other substances that have recently been alive.

- The average majority of biomass energy is produced from wood and wood wastses, followed by solid waste, agricultural waste and landfill gases and the distribution is shown in figure below.

![Biomass Energy](image)

**Type of biomass energy**

- Biomass can be economically produced with minimal or even positive environmental impacts through perennial crops.

- Much of the rural population in developing countries, which represents about 50% of the world’s population, is reliant on biomass, mainly in the form of wood, for fuel.
• Potential future world roles for bioenergy were projected by several researchers as shown in figures below.

<table>
<thead>
<tr>
<th>Source, date</th>
<th>Time frame (year)</th>
<th>Bioenergy contribution</th>
<th>percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Johansson et al, 1993</td>
<td>2025</td>
<td>145</td>
<td>37%</td>
</tr>
<tr>
<td></td>
<td>2050</td>
<td>206</td>
<td>37%</td>
</tr>
<tr>
<td>Shell, 1994</td>
<td>2060</td>
<td>220–222</td>
<td>15–22%</td>
</tr>
<tr>
<td>WEC, 1994</td>
<td>2050</td>
<td>94–157</td>
<td>~15%</td>
</tr>
<tr>
<td></td>
<td>2100</td>
<td>132–215</td>
<td>11–15%</td>
</tr>
<tr>
<td>Greenpeace, 1993</td>
<td>2050</td>
<td>114</td>
<td>19%</td>
</tr>
<tr>
<td></td>
<td>2100</td>
<td>181</td>
<td>18%</td>
</tr>
<tr>
<td>IPCC, 1996</td>
<td>2050</td>
<td>280</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>2100</td>
<td>325</td>
<td>46%</td>
</tr>
</tbody>
</table>

1 See Energy Futures and Scenarios in Chapter 10 References and Further information
2 Bioenergy as a percentage of total primary energy
Source: Adapted from UNDP, 2000

Potential future world roles for bioenergy

• A semi-efficient and ambitious renewable energy scenario has been proposed by Michael Totten as shown in figure below.

Prediction of renewable energy scenario
Activity 11:
Comment briefly about the environmental issues for biomass with respect to climate change, pollution and social impact.

**Hydropower**

- The water in rivers and streams can be captured and turned into hydropower, also called hydroelectric power.
- Hydropower is categorized into micro scale, mini-scale, small scale and large scale
- World hydro production is depicted in figure shown next.

<table>
<thead>
<tr>
<th>Producers</th>
<th>TWh</th>
<th>% of World total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>338</td>
<td>12.4</td>
</tr>
<tr>
<td>Brazil</td>
<td>306</td>
<td>11.2</td>
</tr>
<tr>
<td>United States</td>
<td>306</td>
<td>11.2</td>
</tr>
<tr>
<td>People’s Rep. of China</td>
<td>284</td>
<td>10.4</td>
</tr>
<tr>
<td>Russia</td>
<td>158</td>
<td>5.8</td>
</tr>
<tr>
<td>Norway</td>
<td>106</td>
<td>3.9</td>
</tr>
<tr>
<td>Japan</td>
<td>104</td>
<td>3.8</td>
</tr>
<tr>
<td>India</td>
<td>75</td>
<td>2.8</td>
</tr>
<tr>
<td>France</td>
<td>64</td>
<td>2.3</td>
</tr>
<tr>
<td>Venezuela</td>
<td>61</td>
<td>2.2</td>
</tr>
<tr>
<td>Rest of the World</td>
<td>924</td>
<td>34.0</td>
</tr>
<tr>
<td><strong>World</strong></td>
<td>2 726</td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

*Excludes countries with no hydro production.*

<table>
<thead>
<tr>
<th>Country</th>
<th>% of hydro in total domestic electricity generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway</td>
<td>98.9</td>
</tr>
<tr>
<td>Brazil</td>
<td>83.8</td>
</tr>
<tr>
<td>Venezuela</td>
<td>66.0</td>
</tr>
<tr>
<td>Canada</td>
<td>57.5</td>
</tr>
<tr>
<td>Russia</td>
<td>17.2</td>
</tr>
<tr>
<td>People’s Rep. of China</td>
<td>14.9</td>
</tr>
<tr>
<td>India</td>
<td>11.9</td>
</tr>
<tr>
<td>France</td>
<td>11.4</td>
</tr>
<tr>
<td>Japan</td>
<td>9.9</td>
</tr>
<tr>
<td>United States</td>
<td>7.5</td>
</tr>
<tr>
<td>Rest of the World*</td>
<td>15.2</td>
</tr>
<tr>
<td><strong>World</strong></td>
<td>16.3</td>
</tr>
</tbody>
</table>

**World hydro production**

Geothermal energy

- Geothermal energy is the heat from the Earth. It's clean and sustainable.
- Resources of geothermal energy range from the shallow ground to hot water and hot rock found a few miles beneath the Earth's surface, and down even deeper to the extremely high temperatures of molten rock called magma (Shown in figure below).


Activity 12:
Identify the major world hydropower producer in Asia and Europe and make comparison on the attributes between them.

Geothermal resources
- Temperature variation of earth temperature is depicted in figure below.

Temperature Variation of earth Surface


- There are three type of geothermal steam power plant: dry steam power plant, flash steam power plant and binary cycle power plant such as shown in the following figures.
Binary Cycle Power plant

Hot dry rock resources

Source: Geothermal explorers Ltd, 2004
Currently, there are no commercial applications of this technology. Existing technology also does not yet allow recovery of heat directly from magma, the very deep and most powerful resource of geothermal energy.

Activity 13:
Obtain at least 3 geothermal sites in your region and describe details of the system. (Viz size, technology, reservoir temperature etc)

Geothermal power generation around the end of twentieth century is shown in figure below.

<table>
<thead>
<tr>
<th>Nation</th>
<th>1995 MW_e</th>
<th>2000 MW_e</th>
<th>2005 (est. MW_e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>0.67</td>
<td>0</td>
<td>n/a</td>
</tr>
<tr>
<td>Australia</td>
<td>0.17</td>
<td>0.17</td>
<td>n/a</td>
</tr>
<tr>
<td>China</td>
<td>28.78</td>
<td>29.17</td>
<td>n/a</td>
</tr>
<tr>
<td>Costa Rica</td>
<td>55.0</td>
<td>142.5</td>
<td>161.5</td>
</tr>
<tr>
<td>El Salvador</td>
<td>105.0</td>
<td>161</td>
<td>200</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>0</td>
<td>8.52</td>
<td>8.52</td>
</tr>
<tr>
<td>France</td>
<td>4.2</td>
<td>4.2</td>
<td>20</td>
</tr>
<tr>
<td>Guatemala</td>
<td>0</td>
<td>33.4</td>
<td>33.4</td>
</tr>
<tr>
<td>Iceland</td>
<td>50.0</td>
<td>170</td>
<td>186</td>
</tr>
<tr>
<td>Indonesia</td>
<td>309.75</td>
<td>589.5</td>
<td>1987.5</td>
</tr>
<tr>
<td>Italy</td>
<td>631.7</td>
<td>785</td>
<td>946</td>
</tr>
<tr>
<td>Japan</td>
<td>413.7</td>
<td>546.9</td>
<td>566.9</td>
</tr>
<tr>
<td>Kenya</td>
<td>45.0</td>
<td>45</td>
<td>173</td>
</tr>
<tr>
<td>Mexico</td>
<td>753.0</td>
<td>755</td>
<td>1080</td>
</tr>
<tr>
<td>New Zealand</td>
<td>286.0</td>
<td>437</td>
<td>437</td>
</tr>
<tr>
<td>Nicaragua</td>
<td>70.0</td>
<td>70</td>
<td>145</td>
</tr>
<tr>
<td>Philippines</td>
<td>1227.0</td>
<td>1909</td>
<td>2673</td>
</tr>
<tr>
<td>Portugal</td>
<td>5.0</td>
<td>16</td>
<td>45</td>
</tr>
<tr>
<td>Russia</td>
<td>11.0</td>
<td>23</td>
<td>125</td>
</tr>
<tr>
<td>Thailand</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Turkey</td>
<td>20.4</td>
<td>20.4</td>
<td>250</td>
</tr>
<tr>
<td>USA</td>
<td>2816.7</td>
<td>2228</td>
<td>2376</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>6833</strong></td>
<td><strong>7974</strong></td>
<td><strong>11414</strong></td>
</tr>
</tbody>
</table>

(from Hutterer, 2000)
Solar energy

- The energy comes from processes called
  - solar heating (SH),
  - solar home heating (SHH),
  - solar dryer (SD), and
  - solar cooker (SC),
  - solar water heating (SWH),
  - solar photovoltaic (SPV: converting sunlight directly into electricity), and
  - solar thermal electric power (STEP: when the sun’s energy is concentrated to heat water and produce steam, which is used to produce electricity).

- The major component of any solar system is the solar collector.

![Solar energy collectors](http://www.eia.doe.gov/cneaf/solar.renewables/page/solarthermal/solarthermal.html)

- The three most popular types of SD are
  - box type,
- cabinet type, and
- tunnel type

- Photovoltaic (PV) systems, other than SHH systems, are used for converting solar energy directly to electrical energy.
Wind energy

Wind turbines

- Wind turbines capture the wind's energy with two or three propeller-like blades, which are mounted on a rotor, to generate electricity. Schematic diagram of wind turbine – basic operation

Wind Energy System
Wind turbine

The turbines sit high atop towers, taking advantage of the stronger and less turbulent wind at 100 feet (30 meters) or more aboveground.

Trend of installed wind turbine in the world from 1981 to 2003
<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>Population (Million)</th>
<th>Total capacity installed at end 2004 (MW)</th>
<th>Total capacity installed at end 2004 (watts/capita)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Denmark</td>
<td>5.3</td>
<td>3,117</td>
<td>588.1</td>
</tr>
<tr>
<td>2</td>
<td>Spain</td>
<td>39.4</td>
<td>8,263</td>
<td>209.7</td>
</tr>
<tr>
<td>3</td>
<td>Germany</td>
<td>82.0</td>
<td>16,629</td>
<td>202.8</td>
</tr>
<tr>
<td>4</td>
<td>Ireland</td>
<td>3.7</td>
<td>339</td>
<td>91.6</td>
</tr>
<tr>
<td>5</td>
<td>Luxembourg</td>
<td>0.4</td>
<td>35</td>
<td>87.5</td>
</tr>
<tr>
<td>6</td>
<td>Austria</td>
<td>8.0</td>
<td>606</td>
<td>75.6</td>
</tr>
<tr>
<td>7</td>
<td>Netherlands</td>
<td>15.8</td>
<td>1,078</td>
<td>68.2</td>
</tr>
<tr>
<td>8</td>
<td>Portugal</td>
<td>10.0</td>
<td>522</td>
<td>52.2</td>
</tr>
<tr>
<td>9</td>
<td>Sweden</td>
<td>8.9</td>
<td>442</td>
<td>49.7</td>
</tr>
<tr>
<td>10</td>
<td>Greece</td>
<td>10.5</td>
<td>465</td>
<td>44.3</td>
</tr>
<tr>
<td>11</td>
<td>New Zealand</td>
<td>4.0</td>
<td>168</td>
<td>42.5</td>
</tr>
<tr>
<td>12</td>
<td>Norway</td>
<td>4.5</td>
<td>160</td>
<td>35.6</td>
</tr>
<tr>
<td>13</td>
<td>USA</td>
<td>285.9</td>
<td>6,740</td>
<td>23.6</td>
</tr>
<tr>
<td>14</td>
<td>Australia</td>
<td>19.3</td>
<td>380</td>
<td>19.7</td>
</tr>
<tr>
<td>15</td>
<td>Italy</td>
<td>57.6</td>
<td>1,125</td>
<td>19.5</td>
</tr>
<tr>
<td>16</td>
<td>Costa Rica</td>
<td>4.0</td>
<td>71</td>
<td>18.0</td>
</tr>
<tr>
<td>17</td>
<td>Finland</td>
<td>5.2</td>
<td>82</td>
<td>15.8</td>
</tr>
<tr>
<td>18</td>
<td>UK</td>
<td>59.1</td>
<td>888</td>
<td>15.0</td>
</tr>
</tbody>
</table>

**Wind energy generating capacity by country, 1980 till 2003**

*Source: Worldwatch Institute, 1990*

**Other renewable energy sources**

- Ocean energy, biogas from animal wastes, landfill gas, hydrogen and peat energy are the other RES.
2.3 Fuel Substitutions

- With the traditional sources of fuel depleting, efforts to search for other forms of energy, which are sustainable have been expedited globally.
- Bio-fuels such as methane or compressed natural gas (CNG), propane or liquid petroleum gas (LPG), alcohols, bio-fuels and hydrogen are important fuel substitution.
- Alternative fuels are of interest since they can be refined from renewable feed stocks
- Generally their emission levels can be lower than those of gasoline and diesel fuel engines.

Methane

- Sometime called as town gas. It is formed in nature by the decomposition of vegetable matter and occurs in marshes and sewage gas.
- A gas rich in methane can be obtained by the action of bacteria on animal manure in the absence of air.
- Methane constitutes the bulk of the constituents in natural gas (approximately 93% by volume).
- Methanation is a process for the conversion of carbon monoxide (CO) and hydrogen (H₂) gases into methane (CH₄) and water (H₂O), using nickel catalyst accompanied by heat liberation

\[
\text{CO} + 3\text{H}_2 \Rightarrow \text{CH}_4 + \text{H}_2\text{O} + 7900 \text{ kJ/kg}
\]
If CO₂ is present, it can be methanated by,

\[
CO_2 + 4H_2 \Rightarrow CH_4 + 2H_2O + 4200 \text{ kJ/kg}
\]

**Propane**

- Propane is produced as a product of natural gas processing and petroleum refining. It is also produced during crude oil refining as a by-product of the processes that rearrange and/or break down larger molecular structures to obtain more desirable product such as gasoline and diesel fuels.

- Propane (\(C_3H_8\)) is a saturated paraffinic hydrocarbon. When blended with butane (\(C_4H_{10}\)) or ethane (\(C_2H_6\)), it is designated as liquefied petroleum gas (LPG). A common LPG blend is P92, which are 92% propane and 8% butane.

- LPG is obtained from the lighter hydrocarbon fractions produced during crude oil refining, and the other half from heavier components of wellhead natural gas.

- In vehicles, propane is stored as a compressed liquid, typically from 0.9 to 1.4 MPa. Its evaporative emissions are essentially zero, since it is used in a sealed system. A pressure regulator controls the supply of propane to the engine, and converts the liquid propane to a gas through a throttling process.

- Liquid propane has three-fourths of the energy density by volume of gasoline, so that the fuel economy is correspondingly reduced. The volumetric efficiency and the power are also reduced due to the displacement of about 5% to 10% of the intake air by the propane, and the loss of evaporative charge cooling. It requires about 5o spark advance at lower engine speeds due to its relatively low flame speed.
• Generally the emission concentrations of HC and CO are lower with LPG than gasoline, by 43% and 53% respectively, but the NO\textsubscript{X} level is higher.

LPG fuelled vehicle regulated emission for a 3.1 L engine

<table>
<thead>
<tr>
<th>Emission</th>
<th>Propane (g/km)</th>
<th>Gasoline (g/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC</td>
<td>0.21</td>
<td>0.37</td>
</tr>
<tr>
<td>CO</td>
<td>2.55</td>
<td>5.4</td>
</tr>
<tr>
<td>NO\textsubscript{X}</td>
<td>0.67</td>
<td>0.42</td>
</tr>
</tbody>
</table>

In general propane is clean burning and non-toxic, reliable, good value and safe to use as an alternative energy for domestic (lighting, drying, heating and cooking), transport and industrial applications.
Methanol

- Methanol (CH₃OH) is an alcohol fuel from biomass feed stock also called wood alcohol.
- Its chemical structure is a hydrocarbon molecule with a single hydroxyl (OH) radical.
- The hydroxyl radical increases the polarity of the hydrocarbon, so that methanol is miscible in water, and has a relatively low vapour pressure.
- Since oxygen is part of the chemical structure, less air is required for complete combustion.
- Methanol is toxic, and ingestion can cause blindness and death.
- Methanol has been used as a vehicular fuel since the early 1900s and is used for diesel engines and fuel cells.

Activity 14:
Discuss the importance of cetane and octane numbers for biofuels as compared to fossil fuels.

Ethanol

- Ethanol often called “grain” alcohol (C₂H₅OH) is an alcohol fuel formed from the fermentation of sugar and grain stocks, primarily sugar cane and corn.
- Its properties and combustion characteristic are very similar to those of methanol.
- The raw materials for the biochemical production of ethanol are natural compounds of carbon, hydrogen and oxygen called carbohydrates.
• The chemical synthetic process for the manufacture of ethanol is based on the hydration of the hydrocarbon gas ethylene (C\textsubscript{2}H\textsubscript{4}); thus

\[ \text{C}_2\text{H}_4 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH} \]

• In the hydration process a mixture of ethylene gas and steam at 400\textdegree{}C and 7 MPa is passed over a phosphoric acid catalyst supported on an inert (silica-based). The product consists of ethanol and water vapour, is condensed and purified by fractional distillation.

• Neat ethanol containing 90\% of alcohol can be used as automotive fuel. Blends of gasoline of ethanol can serve as fuel in many automobile engines without fuel system adjustment.

**Hydrogen**

• The combination of hydrogen with oxygen (e.g. from air) results in the liberation of energy, with water as the sole material product; thus,

\[ \text{H}_2 + 0.5\text{O}_2 \rightarrow \text{H}_2\text{O} + \text{Energy} \]

Hydrogen     Oxygen     Water

• Some possibilities are burning with or without flame to produce heat, use as fuel for a gas turbine or for a spark-ignition engine, and generation of electricity in a fuel cell.

• Hydrogen at ordinary temperature and pressure is a light gas with a density only 1/14\textsuperscript{th} that of air and 1/9\textsuperscript{th} that of natural gas under the same conditions. By cooling to the extremely low temperature of -253\textdegree{}C at atmospheric pressure, the gas is condensed to a liquid with a specific gravity of 0.07, roughly 1/10\textsuperscript{th} that of gasoline.
• Liquid and gas hydrogen can be transmitted and distributed by pipeline or compressed into transportable cylinders.

• It can be stored in the form of gas, liquid and hydrides. A number of metals and alloys form solid compounds, called metal hydrides, by direct-reaction with hydrogen gas. When the hydride is heated, the hydrogen is released and the original metal is recovered for further use.

• The applications of hydrogen are for residential, industrial and land vehicle use. When hydrogen is utilized it will be accompanied by little or no atmospheric pollution.

• The methods for producing hydrogen may be classified according to the immediate source of this energy, thus electrical energy (in electrolysis), heat energy (in thermo-chemical methods), fossil fuels, and solar energy.

The use of hydrogen as fuel in modern land vehicle

• In many cases, such as when hydrogen is burned in pure oxygen, in a flameless (catalytic) burner in air, or in a fuel cell with air or oxygen, water is the sole product.
**Bio-Diesels**

- It is a processed fuel that can be readily used in diesel-engined vehicles.
- Biodiesel from the straight vegetable oils (SVO) or waste vegetable oils (WVO) is used as fuels in some modified diesel vehicles.
- Biodiesel refers to alkyl esters made from the transesterification of both vegetable oils and/or animal fats.
- Biodiesel is biodegradable and non-toxic, and has significantly fewer emissions than petroleum-based diesel when burned.
- Biodiesel is a light to dark yellow liquid.
- It is practically immiscible with water, has a high boiling point and low vapour pressure.
- Typical methyl ester biodiesel has a flash point of ~ 150 °C, making it rather non-flammable.
- Biodiesel has a density of ~ 0.86 g/cm³, less than that of water.
- It has a viscosity similar to petrodiesel, the industry term for diesel produced from petroleum.
- It can be used as an additive in formulations of diesel to increase the lubricity of pure Ultra-Low Sulphur Diesel (ULSD) fuel - the sulphur content of the mixture should not be above 15 ppm.
- Much of the world uses a system known as the "B" factor to state the amount of biodiesel in any fuel mix, in contrast to the "BA" or "E" system used for ethanol mixes e.g. Fuel containing 20% biodiesel is labelled B20. Pure biodiesel is referred to as B100.
Methyl esters of crude palm oil and olive oil as diesel substitutes.

Blend of vegetable oil and petroleum-based fuel to form bio-diesel (B20).

Other Fuels For Diesel Engines

- A few other fuels are being considered as diesel substitutes. They are:
  - Dimethyl ether (DME) - DME is an oxygenated fuel produced by dehydration of methanol or from synthesis gas.
Fisher-Tropsch (F-T) fuel - F-T fuel is produced through a catalyzed reaction between a vegetable oil and methanol.

- These alternative diesel fuels have a higher cost, and lower volumetric energy density than diesel fuel, but do produce lower emissions.
- They contain essentially no sulphur or aromatics.
- The use of DME fuel in a heavy duty compression ignition engine will reduce all regulated emissions below the 1998 California ULEV standards.
- The F-T fuel also is known to produce lower regulated emission concentrations i.e. 43% lower HC, 39% lower CO, 14% lower particulates and also 14% lower NO\textsubscript{X} than a typical low sulphur diesel fuel.
3. ASSESSMENT OF ENERGY USE

3.1 Data & Indicator

- The principal energy sources on earth can be categorized into four sources;
  - Solar
  - Nuclear
  - Geothermal
  - Gravitational

- Solar is the most exploited of these sources due to the various convenient forms that it is stored in;
  - Fossil fuel (link to fossil fuel section of Dr Azhar’s)
  - Biomass (link to biomass section of Mazlan’s)
  - Direct solar radiation (link to solar power section of Mazlan’s)
  - Hydro power (link to hydro section of Mazlan’s)
  - Wind (link to wind section of Mazlan’s)

- This is followed by nuclear since it can be sited according to need and convenience.

- Geothermal and Gravitational (tidal power) is limited to geographically opportune places.
World Energy Balance

- We can compare the total world energy balance by taking into account the total annual solar radiation plus other sources of energy and the energy usage.
- Solar radiation balance can be seen in figure below

![World Solar Radiation Balance](image)

World Solar Radiation Balance

- Total annual energy use versus total energy sources can be seen in figure below:
- There is still a very big difference between total annual energy supply from solar source and the annual energy consumption.
- Total solar radiation is not fully exploited
Total Energy Source vs. Annual Consumption

- European energy sources and usage flow diagram (link to European.energy.flow.2005.pdf)

Estimated World Oil Resources

- Estimated world oil resources up to 2025 is given in the figure below
Estimated world oil resources, 1995-2025

- World oil production is given in the figure below

![Graph showing world oil production from 1970 to 2025](image)

**Sources:**
3.2 Benchmarking & Best Practices

- We can look at energy benchmarking from three points of view
  - Energy Production
  - Energy Consumption
  - Major Energy Devices

- What is benchmarking. Benchmark = Current norm.
  - Can be evaluated in terms of “size” and efficiency.

- Energy use can be categorized into six broad sectors:
  - Transportation,
Residential,
Commercial,
Industrial,
Agricultural

Non-Energy Uses

Energy usage in the transportation and residential sectors is largely controlled by individual consumers.

Commercial and industrial energy expenditures are determined by businesses, government entities and other facility managers.

Non-energy use is defined as sectors that use the fuel supplies not to produce energy, but to make products.

- E.g. Use of petroleum to produce plastics, fertilizers and asphalt.

A national energy policy has a significant effect on energy usage across all sectors.

Data for Malaysian Energy Consumption (link to Malaysia.energy.consumption.jpg)

Data for 2005 world energy consumption by sector (link to world.energy.consumption.a.jpg and world.energy.consumption.b.jpg)

**SOURCE**


**Benchmarking** - This can be understood as “current norm” or current “best performance” depending on the context. If we are talking of standards, current norm is meant, but if we are talking about improving performance, then best performance may be used.
Transportation sector

- For
  - Personal
  - Freight transportation.
- Data for Malaysia transport sector energy consumption for 2003 (link to Malaysia.transport.consumption.jpg)
- Transportation sector is not discussed in detail within the scope of this unit. But it takes a major percentage of energy usage (~60%)

Residential sector

- The residential sector refers to private residences, including
  - single-family homes,
  - apartments,
  - manufactured homes and
  - Dormitories.
- Energy use in this sector varies significantly, chiefly due to regional climate differences. On average, about half of the energy used in homes is expended on space conditioning (i.e. heating and cooling the living space).
- Home energy consumption averages:
  - space conditioning, ~50%
  - water heating, 13%
- lighting, 12%
- refrigeration, 8%
- home electronics, 6%
- laundry appliances, 5%
- kitchen appliances, 4%
- other uses, ~2%

**Source:** http://buildingsdatabook.eren.doe.gov/docs/1.2.3.pdf

- In most residences no single appliance dominates, and any conservation efforts must be directed to numerous areas in order to achieve substantial energy savings

**Source:** [http://en.wikipedia.org](http://en.wikipedia.org) “energy conservation”

**Activity 17:**
Find energy consumption average for Malaysian residential sector (or choose another country)

---

**Commercial Sector**

- The commercial sector consists of
  - retail stores,
  - offices (business and government),
  - restaurants,
  - schools and
Energy in this sector has the same basic end uses as the residential sector, in slightly different proportions. Space conditioning is again the single biggest consumption area, but it represents only about 30% of the energy use of commercial buildings. Lighting, at 25%, plays a much larger role than it does in the residential sector.

Commercial buildings usually have the benefit of professional management, allowing centralized control and coordination of energy conservation efforts.

As a result, fluorescent lighting (about 4 times as efficient as incandescent) is the standard for most commercial space, while it remains rare in individual homes.

As most buildings have consistent hours of operation, programmed thermostats and lighting controls are common.

Many corporations and governments also require the Energy Star rating for any new equipment purchased for their buildings.

**Industrial sector**

The industrial sector represents all production and processing of goods, including

- manufacturing,
- construction,
- farming and
- mining.
• In general, this sector's use of space conditioning and lighting is much less significant than the energy used to power heavy machinery and provide heating/cooling for various production processes.

• Increasing costs have forced energy-intensive industries to make substantial efficiency improvements in the past 30 years.

• For example, the energy used to produce steel and paper products has been cut 40% in that time frame, while petroleum/aluminium refining and cement production have reduced their usage by about 25%.

• These reductions are largely the result of recycling waste material and the use of cogeneration equipment for electricity and heating.

**Agricultural sector**

• A sample of agricultural energy use is given; in this case, the one for Canada up to 2004. ([link to agriculture.canada.pdf](#))

**Activity 18:**

1. Choose an area (steam power plant, building energy systems, etc.) and compare the performance index between two chosen countries. Based on the data, suggest areas of potential improvement by the worse performing country

2. Choose two areas and compare their performances between two chosen countries. Would the country with better performance in an area indicate that the other area would also perform better? Suggest factors that may affect this evaluation

**Performance Index** - Key performance parameters of a system. This is different for different systems. For example, thermal efficiency for power plants, but COP for refrigerators. It may be a collection of several parameters
Systems Benchmark Performance

Power Plant Efficiencies

- Global power generation are mainly from
  - Steam turbines
  - Gas turbines, and
  - Nuclear steam turbines

- Breakdown by continent is given in figure. (link to global.generation.turbine.jpg)

- Average efficiencies for coal fired plants is around 46%, while combined cycle plants can achieve more than 58% efficiency. (link to plant.efficiency.jpg)

- Specific CO₂ emissions for various types of plants (link to plant.emissions.jpg)
  - Lignite fired plants are worst followed by coal
  - Gas Cogeneration emits the least carbon dioxide

Air Conditioning Systems Efficiency

- Cooling capacities for Asian countries (link to ac.cooling.capacities.jpg)

- Energy efficiency rating (EER) measures the efficiency with which a product uses energy to function. It is calculated by dividing a product's BTU output by its wattage. (link to ac.median.eer.jpg and ac.sales.weighted.eer.jpg)
4. ENERGY SYSTEM DESIGN AND ANALYSIS

4.1 Introduction of Energy System Design

- Energy systems is a term encompassing activities of moving, transforming, or transferring energy through a fluid as the working medium i.e. conversion of energy forms.

- Here the focus is on thermal systems requiring expertise in the field of thermodynamics, fluid mechanics and heat transfer.

- A comprehensive definition of design is given by the Accreditation Board of Engineering and Technology (ABET).

- Energy system design is the process of devising an energy system, component, or process to meet the desired needs in energy manipulation. [click for animated flow chart]
Project definition
- Gives a brief description of the product to be designed

Develop preliminary specification and constraints
- Set of requirements that the product should satisfy
- Specifications reflect the requirements of end-user

Develop detailed specification and concepts, evaluation, and performance feasibility study
- Conceptualise
- Screen the different concepts and choose for feasibility study
- In the feasibility study one should use available information of similar systems to evaluate the concepts

Proceed with detailed design and economical analysis if required
- Starts with the information gathered including the requirements and constraints
- The algorithm depend on the system to be designed
- Should include the relevant standards or coded that need to be satisfied
- Complete the design prepare the appropriate drawings [click for help text] (link to Help Text for design.doc)

Present design with results and economic analysis
- Prior to fabrication, necessary approval and decision must be sought
- May entail reports, detail drawings and presentation
- Modification need to be incorporated

Fabricate and test prototype
- Prototype to be tested to identify any problems and practicality of design
- Some further modifications may be required

Manufacture and market product
- The number of units may depend on market considerations
- Depending on the reaction of end user further modifications may be required
4.2 Energy System Analysis

Power Plant

- Power plant is a facility which is specially constructed for the generation of electric power. [link to compedu animation of power plant]

- The basic components in a steam power plant burning fossil fuel is
  - Boiler – [link to relevant component]
  - Turbine – [link to relevant component]
  - Condenser – [link to relevant component]
  - Feedwater pump – [link to relevant component]

Heating, Ventilating and Air-Conditioning Systems

- HVAC is required to maintain the required temperature and humidity in living spaces for both residential and commercial sectors

- Maintains a certain physical space at a cold temperature for a refrigeration system (cooling) and at a high temperature for a heat pump system (heating)
• The components of a HVAC system are
  
  o **heating:** it is accomplished through a high-temperature source, either a fossil-fired furnace that heats the air directly, or circulating the heated water in conditioned spaces.
  
  o **cooling:** it is accomplished by using a vapour compression refrigeration system.
  
  o **dehumidification:** it is accomplished by cooling the humid ambient air below its dew point and then to heat it. Desiccant can also be used to remove moisture.
  
  o **Associated ducts and fans.**
Typical AC System

- Water is cooled in the evaporator (Chiller) of a refrigeration system and circulated to the cooling coils.
- Cooling coils located in vent ducts.
- Allows for refrigeration equipment to be centrally located.
- The cooling coil, chiller and condenser are all heat exchangers. Whether they move heat to or from air or water or refrigerant is merely a matter of design.
- Almost all large chillers use shell and tube evaporators with water flowing through the tubes.

Activity 19:
Design a solar assisted water heating system for domestic use – to provide required specifications as per a project definition data sheet.
5. ENERGY CONSERVATION

Introduction

- The industrial sector is one of the two largest consumers of energy in a country (true for Malaysia), rivalled only by the transport sector [pie chart on distribution of energy consumption in the country by sectors]

- The important aspects of an Energy Management Systems (EMS) are:
  - Management commitment
  - Establishing Committee and responsibilities
  - Planning & Organizing - Objectives and Target Setting
  - Conducting System Audits
  - Implement Action Plan
  - Monitoring and Verification
  - Periodic communication to employees (Reporting)
5.1 Energy Accounting

- An important aspect of energy auditing program is to be able to measure where you are and determine where you are going.
- Initial data on energy consumption for a company site is normally represented in a table of fuels and energy delivered for each of the twelve months of a particular year. [Click for table]

Table below illustrates the assembly of the table in common units of kWh for the case of coal, oil, gas and daytime and night time electricity usage.

<table>
<thead>
<tr>
<th>Year</th>
<th>kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month 2006</td>
<td></td>
</tr>
<tr>
<td>January</td>
<td></td>
</tr>
<tr>
<td>February</td>
<td></td>
</tr>
<tr>
<td>November</td>
<td></td>
</tr>
<tr>
<td>December</td>
<td></td>
</tr>
</tbody>
</table>
Electricity conversion to energy, use 3.60 MJ/kWh always ensure correct conversion factors

- Using an X-Y scatter diagram to plot the relationship between energy consumption data versus production sometimes is clearer when production rate is spasmodic and not easily related to energy consumed.[click for graph]
- The slope of the best fit line identifies the sensitivity of the production rate to energy consumption. The intercept of the line with the energy consumption axis gives the energy use with no production,

![Produced vs consumed energy chart](image)

5.2 Energy Audit

- The energy audit is an application of the First Law of Thermodynamics and represents a balance of energy inputs, outputs and throughputs for the thermal system under consideration.
- In general the energy balance equation may be written:
  - \( \text{Energy Input} = \text{Energy Used} + \text{Energy Losses} \)
- The accounting of the terms in the equation is accomplished by means of a site energy survey called an audit.
- An energy audit serves the purpose of identifying where a building or plant facility used energy and identifies energy conservation opportunities.
Basically audit can be categorized into 3 major types:

- **Preliminary Audit** – Simple, mainly low or no cost [link to Help Text for energy audits.doc]
- **Detailed Audit** – Systematic, mainly medium or high cost [click for help text] (link to Help Text for energy audits.doc)
- **Investment Grade Audit** – Capital Intensive [click for help text] (link to Help Text for energy audits.doc)

Audits depend on the type of facility. Example a industrial audit may emphasize on the energy facilities (energy conversion systems), production facilities (energy utilization) and the outputs.
Activity 20:
List the main component in a factory (give details on type of factory) that an audit may have to concentrate on and discuss the reason for these selections. Prepare a check list for each component.

For convenience it is useful to display the plant information in the form of histograms or pie charts.

An Energy Efficiency Index (EEI) is one of the Key Performance Indicators (KPI) to track the performance of energy consumption – sometimes known by other names such as Specific Energy Consumption (SEC), Specific Energy Ratio or Energy Index. Such indexes are normalised to parameters taking into account differences in site conditions. For example:

\[
\frac{\text{kWh}}{\text{employee}}, \quad \frac{\text{kWh}}{\text{unit floor area}}, \quad \frac{\text{kWh}}{\text{manufactured article}}, \quad \frac{\text{kWh}}{\text{mass of product}}
\]
Legislation Concerning Rational Energy Use

The legal basis for the energy efficiency requirement for end-use equipment is concerned with rational use of energy by factories, buildings, and equipment.

The legislation should establish a general legal framework to secure the conservation of energy resources and the efficient use of energy and industrial potential.

It is of utmost importance to have an international cooperation in the field of rational energy use. The main lines of international cooperation in the field of rational energy use are, as follows:

**Activity 21:**
The following space heating energy performance indicators are relevant to University buildings. The units are kWh/m², where area refers to the building floor area and energy refers to space heating energy usage.

<table>
<thead>
<tr>
<th></th>
<th>kWh/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good Performance</td>
<td>&lt; 325</td>
</tr>
<tr>
<td>Satisfactory Performance</td>
<td>325 - 355</td>
</tr>
<tr>
<td>Poor Performance</td>
<td>&gt; 355</td>
</tr>
</tbody>
</table>

Compare an estimated performance indicator for your building with the above figures and comment on the validity of such a comparison.
Technology transfer, technical assistance and industrial joint ventures subject to international property rights regimes and other applicable international agreements;

- harmonization of national energy efficiency standards with international ones, as well as achieving mutual recognition of certification results.

- mutually beneficial exchange of energy efficient technologies with foreign and international organizations / universities.

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**Activity 22:**
List the legislation with respect to the rational use of energy that are presently enforced in your country. If none, what are the most important areas /aspects that need to be implemented. Discuss the measures that need to be taken in order to effectively implement the state policy elements in the field of rational energy use.

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**Promotion of International Energy Efficiency Measures**

- It is of utmost importance to have an international cooperation in the field of rational energy use.

- The main lines of international cooperation in the field of rational energy use are, as follows:

  - "the rational use of energy" means improving efficiency to the maximum level in the process of consuming energy for a specific objective for the purpose of achieving the same objective with less energy consumption.
o mutually beneficial exchange of energy efficient technologies with foreign and international organizations;
o implementation of joint interstate projects aimed at improving energy efficiency;
o participation in international projects in the field of rational energy use;
o harmonization of national energy efficiency standards with international ones, as well as achieving mutual recognition of certification results.
o Technology transfer, technical assistance and industrial joint ventures subject to international property rights regimes and other applicable international agreements; and
o Training and education:— exchanges of energy managers, officials, engineers and students;— organization of international training courses.
6. WAY FORWARD

6.1 OPPORTUNITIES

Speculation of Future Energy

- Space energy - future space exploration could yield a number of energy sources.

- Hydrogen Fuel - chemical energy storage like in other batteries. As an energy source;
  - in fuel cell battery to convert the chemicals hydrogen and oxygen into water, and in the process, produce electricity.
  - can be burned (less efficiently than in a fuel cell) in an internal combustion engine.

- Solar power satellites – cells placed on orbiting platforms in 24-hour sunlight. The energy is beamed to earth as microwaves to receiving antennas

- Fission Power - Uses the nuclear fission of heavy elements to release energy that drives a heat engine.
  - Fissionable materials could theoretically be obtained from asteroid mining.
  - Fission power's long-term sustainability depends on the amount of uranium and thorium that is available to be mined
• Fusion Energy - Uses the nuclear fusion of isotopes of hydrogen to release energy that drives a heat engine.
  
  o Fusion power's long-term sustainability depends on the amount of lithium and deuterium

Deuterium-Tritium fusion diagram.

Global Energy Trend & Forecast

• Forecast and trend of energy production depend on the ability of energy producers to have access to natural resources

• World primary energy demand is projected to increase by more than half from year 2002 to 2030.

• Fossil fuels still dominates the energy supply.

• World energy resources are enough to meet the increases of energy demand but far form the geographically distributed.

• Oil will remain the most heavily traded fuels.

• Developing countries will be responsible for 70% of the increase in global CO₂ emissions from 2002 to 2030
World Energy Demand of Fuel


World Primary Energy Production by Region


World Energy-Related CO₂ Emission by Region

6.2 BIG PICTURE

International Energy Organization

- Play important role for supporting any energy programme and development in term of technical or non-technical support and also financial support.

- Conducts a broad programme of energy research, energy policy making, energy security, economic development, environmental sustainability, data compilation, and publications.

- Also acting as an information source on energy, promoting and developing alternate energy sources and multinational energy technology co-operation

- Two example of international organization;
  - IEA is acts as energy policy advisor to 26 member countries in their effort to ensure reliable, affordable and clean energy for their citizens.
  - BP is a global company focusing on the activities of exploration and production of crude oil and natural gas, refining, marketing, supply and transportation; and the manufacture and marketing of petrochemicals.

- Others international energy organization:
  - ISEO - International Sustainable Energy Organization
  - OECD - Organisation for Economic Co-operation and Development
  - WEEA - World Energy Efficiency Association
  - NREL - National Renewable Energy Lab
  - CREST - The Centre for Renewable Energy and Sustainable Technology

Activity 23:
What are the expected prospects of a particular renewable energy as substitutes for fossil fuels in your country?
Some of well known international companies, agency and organization

International Collaboration

- Aim to improve cooperation and information exchange between countries that have national programmes in energy research, development and deployment.

- Example activities within the collaborative works such as facilitate cooperation to develop new and improved energy technologies, energy security, economic and social development, and environmental protection.

- The international collaboration offers many benefits including the ability to:
  - Changing and sharing knowledge and expertise
  - Build a common understanding of the technical basis for issues.
  - Changing technologies
  - Strengthen and enhance the quality of R&D outputs.
  - Contribute to energy policy development
  - Disseminate information on technology capabilities

- Examples of international collaboration:
  - IEA Bioenergy – 1978, cooperation and information exchange in bioenergy research
The Energy Technology Data Exchange (ETDE), is a worldwide, growing consortium of countries that share energy-related scientific and technical information.

**Energy Policies**

- The manner a given entity (often governmental) has decided to address issues of energy production, distribution and consumption.
- The attributes of energy policy may include legislation, international treaties, incentives to investment, guidelines for energy conservation, taxation and other public policy techniques.
- There are a number of important determinants of energy policy that has to satisfy the energy demand.
  - The efforts to minimise the costs to the nation arising from the energy sector
  - Guarantee a supply not subject to unacceptable constraints, either economic or political.
  - Deals with technical progress. In the short and medium term, it will influence the amount of financial incentives given to research and development activity in the energy sector and in linked sectors.
  - Will affect the energy demand by improvement of energy efficiency, by new products using energy, and by making available new energy forms.
  - The acceptable or consideration of environmental impact and its future

- Sample of International Energy Policy – Kyoto Protocol
o An agreement made under the United Nations Framework Convention on Climate Change (UNFCCC). Countries that ratify this protocol commit to reduce their emissions of carbon dioxide and five other greenhouse gases.

o Negotiated in Kyoto, Japan in December 1997

o Covers more than 160 countries globally.

o The goal is to lower overall emissions of six greenhouse gases; carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, HFCs, and PFCs - calculated as an average over the five-year period of 2008-12.

o The objective is the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

Full text of the Kyoto Protocol → http://unfccc.int/resource/docs/convkp/kpeng.html

- Sample of Energy Policies of Developed Country – United Kingdom

  o The energy policy of the United Kingdom has achieved success in reducing energy intensity, reducing energy poverty and maintaining energy supply reliability to date.

  o Environmental Issue – the policy has an ambitious goal to reduce carbon dioxide emissions for future years, but it is unclear whether the programs in place are sufficient to achieve this objective.

  o Energy self sufficiency - the policy does not address this issue, other than to concede historic energy self sufficiency is currently ceasing to exist.

  o Transport - the policy has a historically good policy record encouraging public transport; however, the policy does not significantly encourage hybrid vehicle use or ethanol fuel use, which
programs represent the most viable near term means to gain control over rising transport fuel consumption.

- Renewable energy - the policy has laudable and attainable goals for wind and tidal energy, but it has acted inconsistently to stimulate these sectors.

See main article → Energy policy of the United Kingdom

• Sample of Energy Policies of Developing Country - Thailand

- The energy policy of Thailand is characterized by,
  - increasing energy consumption efficiency,
  - increasing domestic energy production,
  - increasing the private sector's role in the energy sector,
  - increasing the role of market mechanisms in setting energy prices.

- These policies have been consistent since the 1990's, despite various changes in governments. The pace and form of industry liberalization and privatization has been highly controversial.

See main article → Energy Industry Liberalization and Privatization Thailand

Activity 24:
What are the basic determinants of your national energy policy. Comments on short-term and long-term implication of the policy.
References

Books, journals and papers


Website

1. www.auburn.edu/~smith01/notes/nuenergy.htm


Glossaries

**Acid rain**  The fallout of acidic particles or any type of precipitation - rain, fog, mist, or snow - that is more acidic than normal.

**Anthropogenic**  Man-made pollution.

**Biomass**  Biomass is organic material made from plants and animals. And contains stored energy from the sun.

**BTOE**  Billion ton of oil equivalent.

**Butterfly effect**  The consequences of an action taken by an irresponsible individual in City A may affect you on the other side of the globe.

**Diesel Fuel**  A mixture of liquid hydrocarbons used as fuel in diesel (compression ignition) engines.

**Emissions trading**  An administrative approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants.

**Fluid mechanics**  Analysis of the continuous deformation of a fluid under the action of a shear force.

**Gasoline**  Straight-run gasoline is obtained by direct distillation of petroleum (crude oil). The other components are products of oil refinery treatment.

**Geothermal (power)**  Electricity generated by utilizing naturally occurring geological heat sources.

**Greenhouse effects**  An effect which traps heat in the atmosphere similar to the effects produced by the glass walls of a greenhouse.

**Greenhouse gases**  CO₂, CH₄, N₂O, CHCs, PFCs, SF₆.

**Hydrowater**  Harnesses the energy of moving or falling water.

**Large scale hydropower**  Large-scale hydropower which has a capacity of more than 30 MW.

**Micro scale hydropower**  Micro hydro power, which has a capacity of 100 kW or less.

**Mini-scale hydropower**  Mini hydro power, which has a capacity of 10kW to 100kW.

**Nuclear energy**  Any nuclear process in which the total mass of the products is less than the mass before interaction is accompanied by the release of energy.

**Ocean (energy)**  Ocean energy draws on the energy of ocean waves, tides, or on the thermal energy (heat) stored in the ocean.

**OECD**  Organisation for Economic Co-operation and Development.

**Small scale hydropower**  Small hydro power refers to facilities with a generating capacity of 100 kW to 30 MW.

**Solar cooker (SC)**  Solar cooker or solar oven is a way of harnessing the sun's power to cook food.

**Solar dryer (SD)**

**Solar heating (SH)**  Solar heating is a style of building construction which uses the energy of sunshine to provide heat in a structure.

**Solar home heating (SHH)**

**Solar photovoltaic (SPV)**  Is a solar power technology that uses solar photovoltaic arrays or solar cells to provide electricity.
<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar thermal electric power (STEP)</td>
<td>Solar thermal electric power plant generates heat by using lenses and reflectors to concentrate the sun's energy</td>
</tr>
<tr>
<td>Solar water heating (SWH)</td>
<td>A solar water heater is a way to generate hot water.</td>
</tr>
<tr>
<td>Solar(power)</td>
<td>Solar power is the technology of obtaining usable energy from the light of the Sun</td>
</tr>
<tr>
<td>space conditioning System</td>
<td>Heating and cooling the living space</td>
</tr>
<tr>
<td>The ozone layer</td>
<td>A thin layer of ozone, $O_3$, molecules in the stratosphere 10 – 40 km above the earth’s surface which absorbs high energy solar radiation incident upon the planet</td>
</tr>
<tr>
<td>Thermodynamics</td>
<td>Relationship between the properties of a substance and their changes between two states</td>
</tr>
<tr>
<td>WCED</td>
<td>World Commission on Environment and Development</td>
</tr>
<tr>
<td>Wind (power)</td>
<td>Wind power is the conversion of wind energy into more useful forms, usually electricity using wind turbines</td>
</tr>
<tr>
<td>Wind turbines</td>
<td>Wind turbine is a machine for converting the kinetic energy in wind into mechanical energy</td>
</tr>
</tbody>
</table>