Energy Conversion ENME 531

Introduction

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Outline- Introduction

- Units
- Energy forms and conversion
- Energy resources
- Economic Analysis

Units

Energy: Joule (J), kJ = 10^3J, MJ = 10^6J = 10^3kJ, GJ = 10^9J.

Large commercial units:

ton of coal equivalent (t.c.e) = 2.9 x 10^{10}J = 29GJ

One barrel oil = 6.1 x 10^9J

One ton oil = 4.47 x 10^{10}J

One ton coal = 2.9 x 10^{10}J

Electrical energy: kWh = 1kW*1hour = 3.6 MJ

Power units: Watt (W), kW, and MW.

Energy & Power

- **Energy** is the ability to do work.
- **Power** is the rate of doing work, that is, the *rate* at which energy is converted from one form to another, or transmitted from one place to another.
- The main unit of measurement of energy is the joule (J) and the main unit of measurement of power is the watt (W), which is defined as a rate of one joule per second.

Energy forms

Forms of energy include:

- Chemical energy stored in chemical bonds of molecules.
- Mechanical energy such as kinetic energy of moving bodies, potential energy.
- Thermal energy: energy in form of heat or internal energy.
- Electrical energy of moving charge or current.
- Electrochemical such as energy in batteries.
- Nuclear energy: involved in nuclear reactions where content of nucleus is affected

Energy conversion

- Transformation of energy from one form to another is known as energy conversion.
- Such conversion processes normally is accompanied by energy efficiencies and losses.
- Some losses are subjected by laws of thermodynamics, such as in heat engines, while others are controlled by technology and conversion systems.

Modern Energy Conversion Sequences

Heating of Buildings:

- Gas, oil, biomass → heat
- Solar → heat

Electricity Generation:

- Coal, gas, nuclear → heat → mechanical → electricity
- Hydro → mechanical → electricity
- Wind → mechanical → electricity
- Solar → Electricity

Transportation:

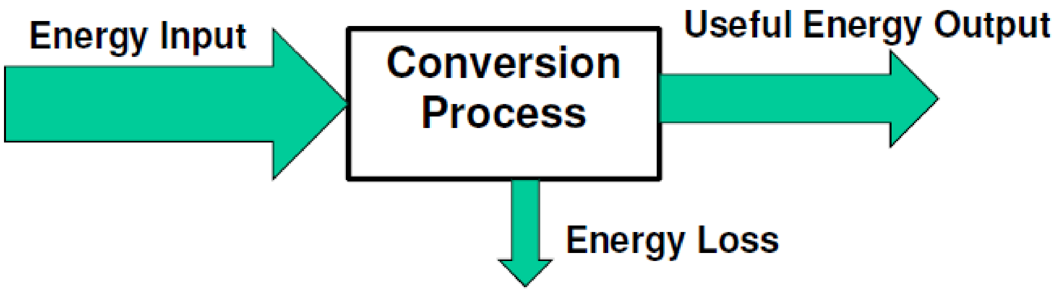
- Oil → gasoline, diesel, jet fuel → heat → mechanical
- Biomass → ethanol → heat → mechanical
- Fuel cell cars: Gas → hydrogen → electricity → mechanical
- Hybrid cars: Gasoline → mechanical → electricity → battery → electricity → mechanical

Direct & non direct conversion

- Direct from available form to electricity.
- Non direct from fuel to electricity via a heat engine.
- Examples of direct conversion;
  - Solar cells; Solar to electricity (PV)
  - Fuel cell; fuel to electricity

Energy conversion

Key Metric: Conversion Efficiency



- When producing work (mechanical or electricity):

  η = Work Output / Energy Input

- When producing energy carriers (diesel, hydrogen):

  η = Energy Content of Product / Energy Input

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Conversion Efficiencies

Conversion	Type	Efficiencies
Natural Gas Furnace	Chemical → Heat	90-96%
Internal combustion engine	Chemical → Mechanical	15-25%
Power Plant Boilers	Chemical → Heat	90-98%
Steam Turbines	Heat → Mechanical	40-45%
Electricity Generator	Mechanical → Electricity	98-99%
Gas Turbines	Chemical → Mechanical	35-40%
Hydro	Grav. Potential → Mechanical	60-90%
Geothermal	Thermal→ Mech→ Electricity	6-13%
Wind	Kinetic → Mech→ Electricity	30-60%
Photovoltaic Cells	Radiation → Electricity	10-15%
Ocean Thermal	Thermal→ Mech→ Electricity	1-3%

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Energy resources classification

Energy resources may be classified :

1. Solar energy: source of other energy forms on earth.
   - Wind energy: sun radiation heats air generating wind which is a form of K.E.
   - Hydro energy: water falls and rivers water evaporation by solar energy, then falls as rain forming rivers and water falls.
   - Wave energy: resulting from wind.
2. Geothermal energy: heat generated by decay of radioactive elements inside the earth. Geothermal energy may be used in thermal form for heating and in power cycles for electricity generation.
3. Nuclear energy: its source as binding energy of atom constituents. Forms of nuclear energy include fission energy and fusion energy as well as radioactivity.

Energy Resources

- Energy for practical purposes can be divided into two classes:
  - ➢ Renewable energy: obtained from the continuing current of energy in the natural environment.
  - ➢ Nonrenewable energy: obtained from stores of energy that is released by human interactions

Nonrenewable energy resources

- Fossil and nuclear fuels are often termed non-renewable energy sources.
- This is because, although the quantities in which they are available may be extremely large, they are nevertheless finite and so will in principle ‘run out’ at some time in the future.

Fossil fuels

- The fossil fuels originated in the growth and decay of plants and marine organisms that existed on the earth millions of years ago.
- Coal was formed when dead trees and other vegetation became submerged under water and were subsequently compressed, in geological processes lasting millions of years, into concentrated solid layers below the earth's surface.
- Oil and associated natural gas originally consisted of the remains of marine organisms that slowly accumulated into layers beneath the earth's oceans and were gradually transformed, through geological forces acting over a long period of time, into the liquid and gaseous reserves.

Nuclear energy

- Nuclear energy is based on the very large quantities of energy that are released when the nuclei of certain atoms, e.g uranium-235 and plutonium-239, are induced to split or 'fission'.
- The complete fission of a kilogram of uranium-235 should produce,, as much energy as the combustion of over 3000 tons of coal.
- The heat generated by nuclear fission in a nuclear power station is used to raise high-pressure steam which then drives steam turbines coupled to electrical generators, as in a conventional power station.

Renewable energy

- Renewable energy is the term used to describe energy flows that occur naturally and continuously in the environment,
- such as energy from solar, wind, waves or tides.
- The origin of the majority of these sources can be traced back to either the sun (energy from the sun helps to drive the earth's weather patterns) or the gravitational effects of the sun and the moon.
- This means that these sources are essentially inexhaustible.

Water power resources

- Power extracted from water can include:
  - hydroelectric power from rivers and dams,
  - ocean thermal power,
  - wave power and
  - tidal power.

Solar energy

- The sun has a surface temperature of 6000 °C, maintained by continuous nuclear fusion reactions between hydrogen atoms within its interior. the sun should continue to supply power for another 5 billion years.
- Solar energy is equivalent to about 15000 times humanity's present rate of use of fossil and nuclear fuels
- All the energy stored in Earth's reserves of coal, oil, and natural gas is matched by the energy from just 20 days of sunshine.
- Each square meter collects the approximate energy equivalent of almost a barrel of oil each year, or 4.2 kilowatt-hours of energy every day.
- Ways of capturing and using the sun's energy, including photovoltaic cells, active solar energy, passive solar energy and concentrating solar power systems.

Wind energy

- Wind energy is the kinetic energy that is found in moving air.
- Like all forms of energy, wind energy is created as a result of the sun.
- Winds are caused by the uneven heating of the surface and the atmosphere by the sun. The sun heats land and water, and the heat from those areas is absorbed by the surrounding air.
- When the air reaches a certain temperature, it begins to quickly rise upwards. This results in a low pressure area at ground level and a higher pressure area above.
- Air naturally moves from high pressure zones to low pressure zones. This movement causes wind.

Geothermal energy

- Geothermal ("Earth-heat") energy comes from the residual heat left over from the Earth's formation and from the radioactive decay of atoms deep inside the Earth.
- This heat is brought up to the Earth's crust by molten rock (magma) and by conduction through solid rock.
- There it raises the temperature of the Earth's surface and of groundwater trapped in the fissures and pores of underground rock, forming zones called hydrothermal (hot water) reservoirs.

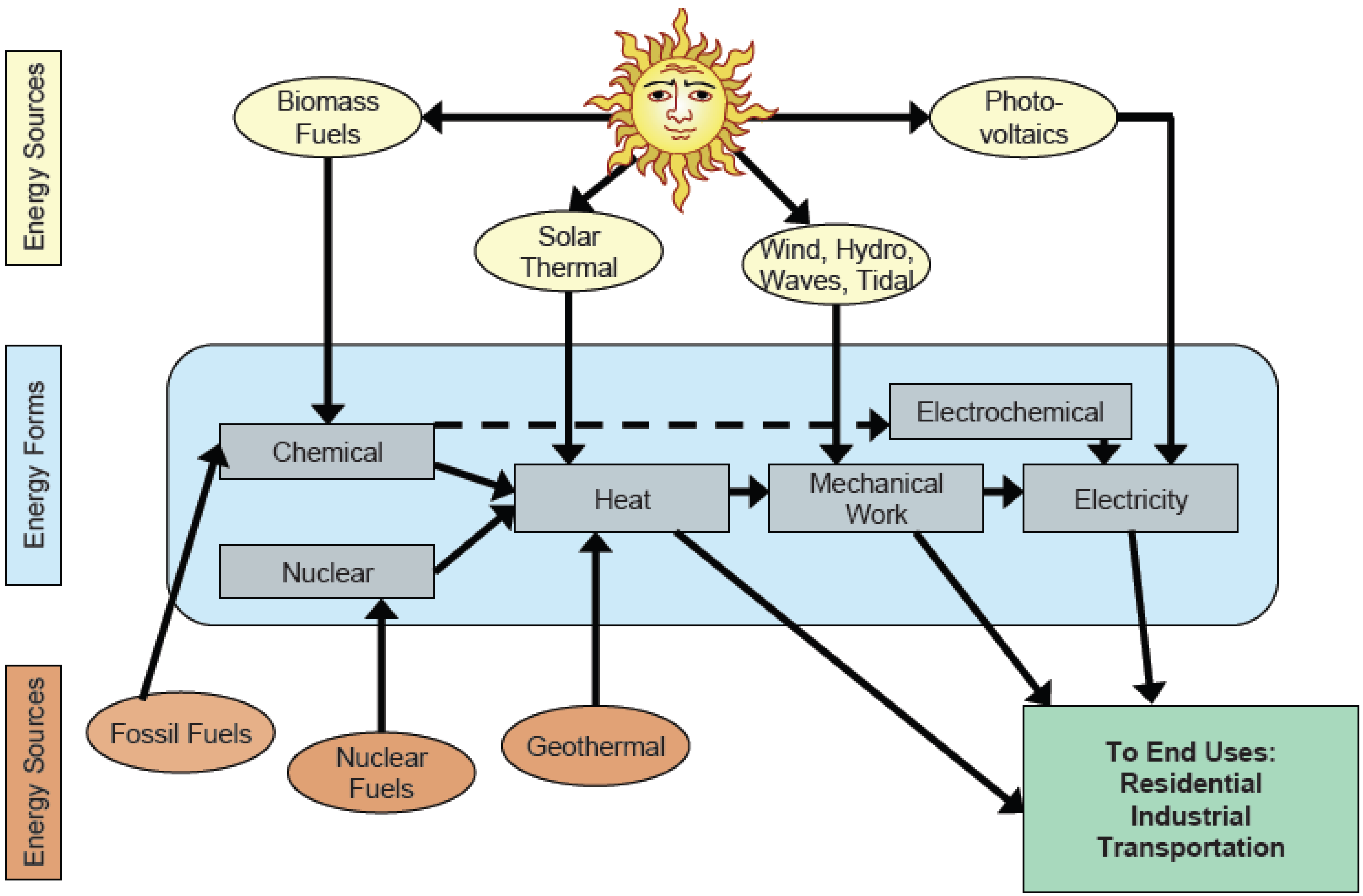
Geothermal applications

- Geothermal energy can currently be harnessed in three different ways:
  - Electricity production is possible with the best (hottest) hydrothermal resources.
  - Lower-temperature hydrothermal resources can be used directly for space and water heating.
  - Geothermal heat pumps (GHPs) can be used for space heating and cooling anywhere in the country.

Biomass

- Biomass is any organic material derived from plants or animals — essentially all energy originally captured by photosynthesis.
- Domestic biomass resources include;
  - agricultural and forestry residues,
  - municipal solid wastes,
  - industrial wastes, and
  - terrestrial and aquatic "energy crops" grown solely for energy purposes.

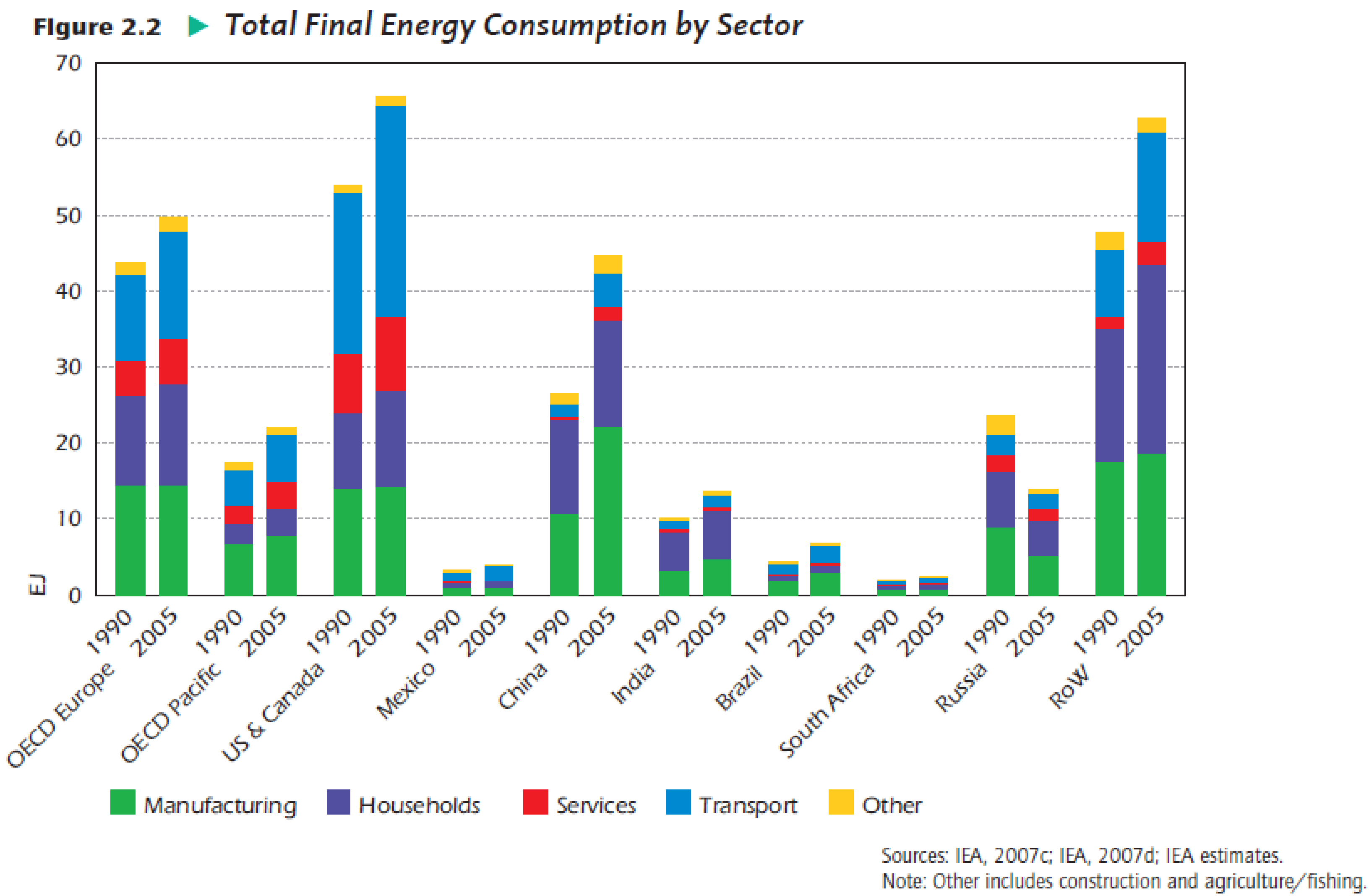
Energy Sources, Conversions and Use



Energy & environment

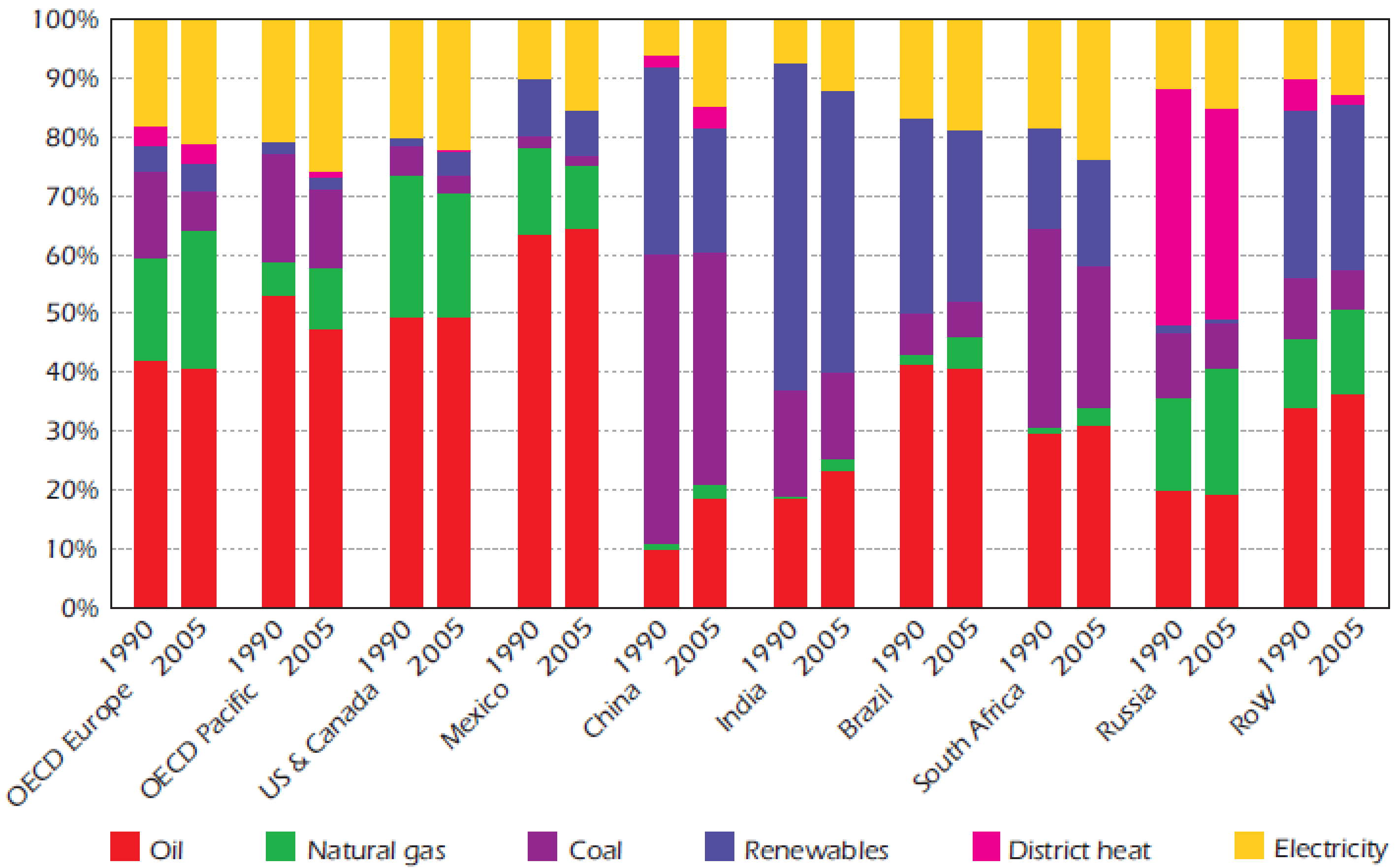
- Air, water, soil pollution
- Global warming- green house gases
- Resource depletion – energy conservation and efficiency
- Sustainability: environment- economics- social

World Energy consumption by sector



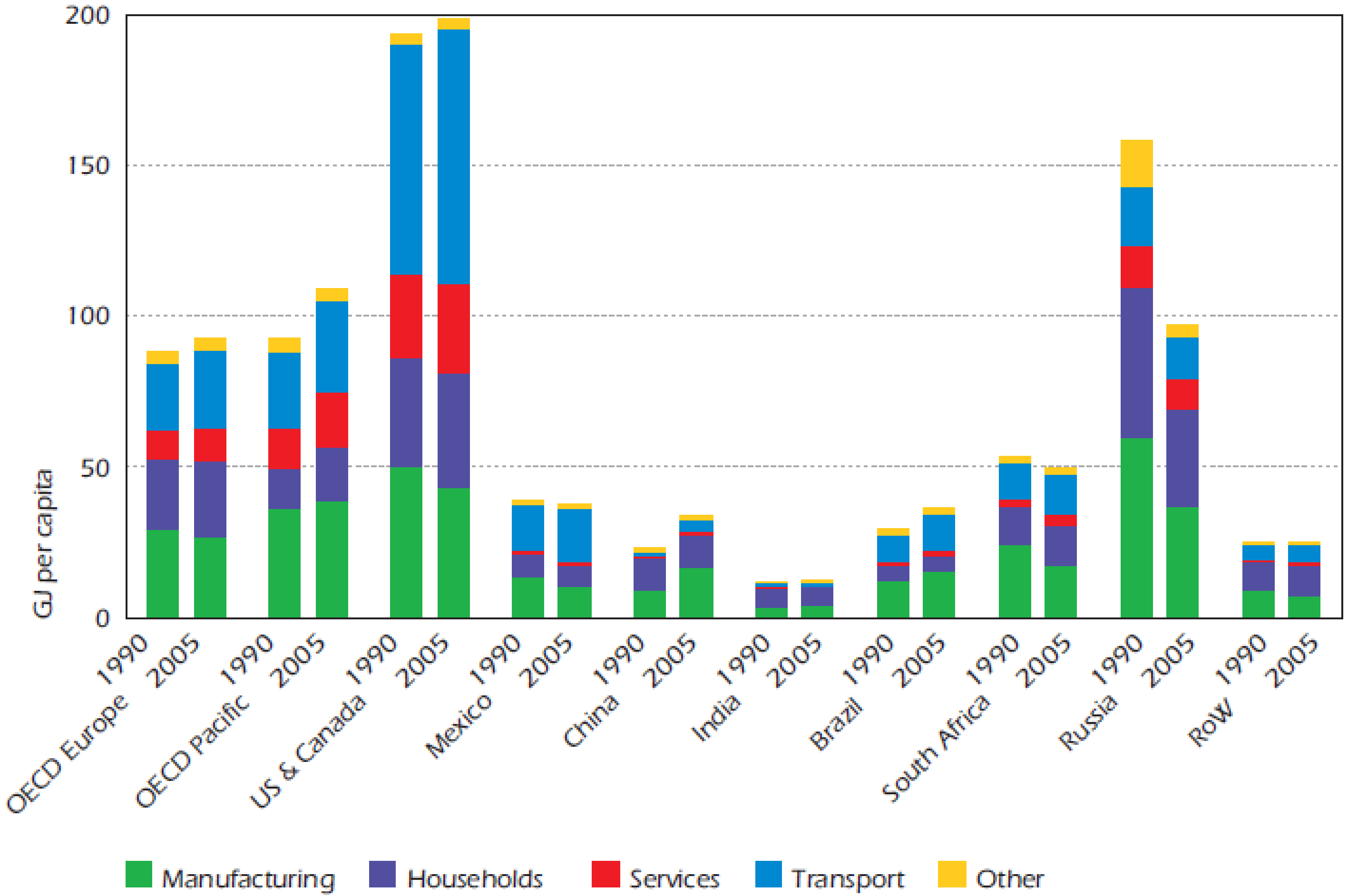
Energy consumption by source

Figure 2.3 ▶ ***Total Final Energy Consumption by Energy Commodity***



Sources: IEA, 2007c; IEA, 2007d; IEA estimates.
Note: Excludes fuel use in electricity and heat production.

Energy consumption per capita

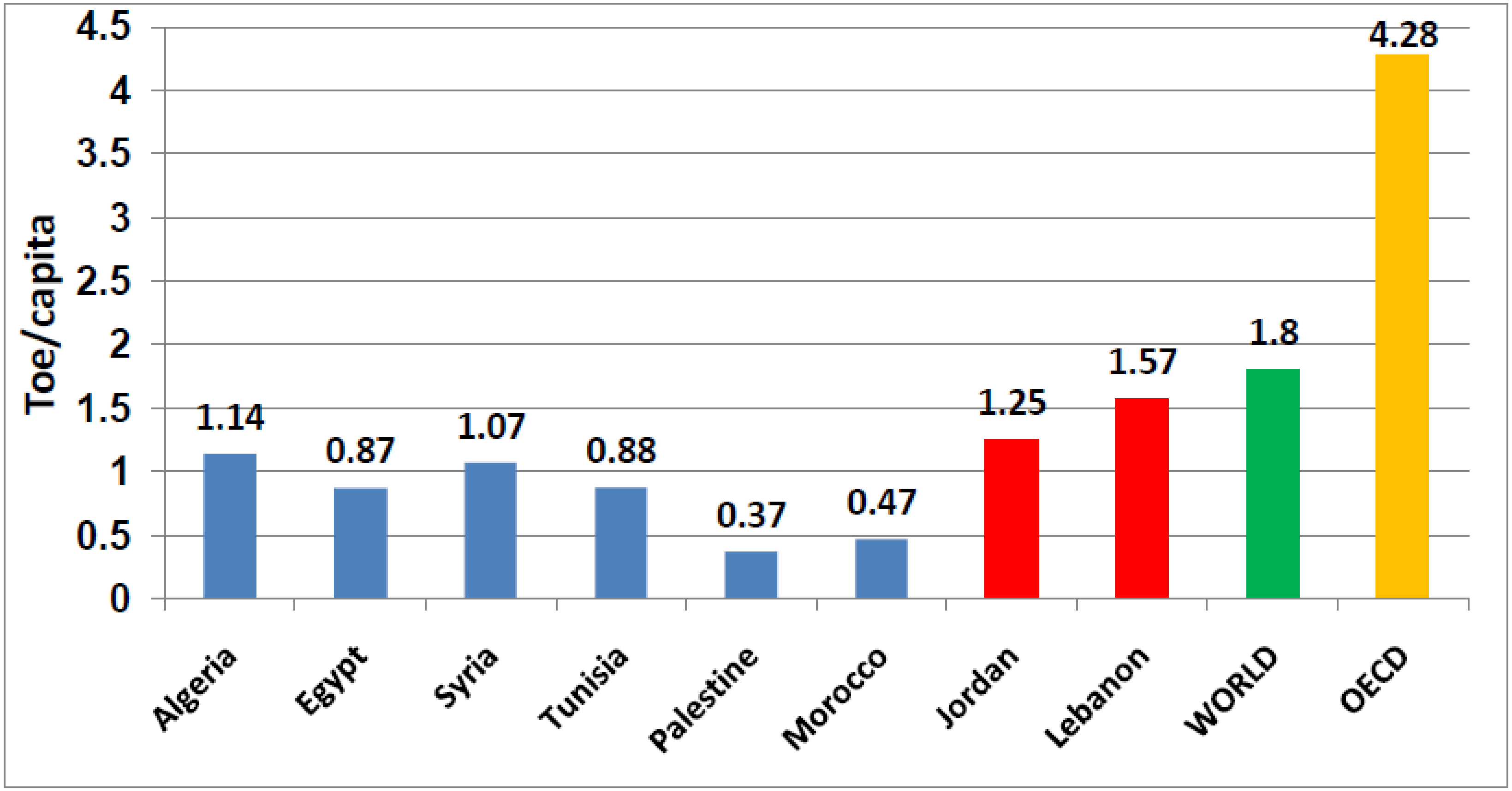


Sources: IEA, 2007c; IEA, 2007d; IEA estimates.
Note: Other includes construction and agriculture/fishing.

Energy consumption

- Per capita energy consumption is highest in USA (12 t.c.e /capita) then   U.K (6 t.c.e /capita).
- Energy consumption is related to GNP.
- Rule of energy conservation and rational use of energy

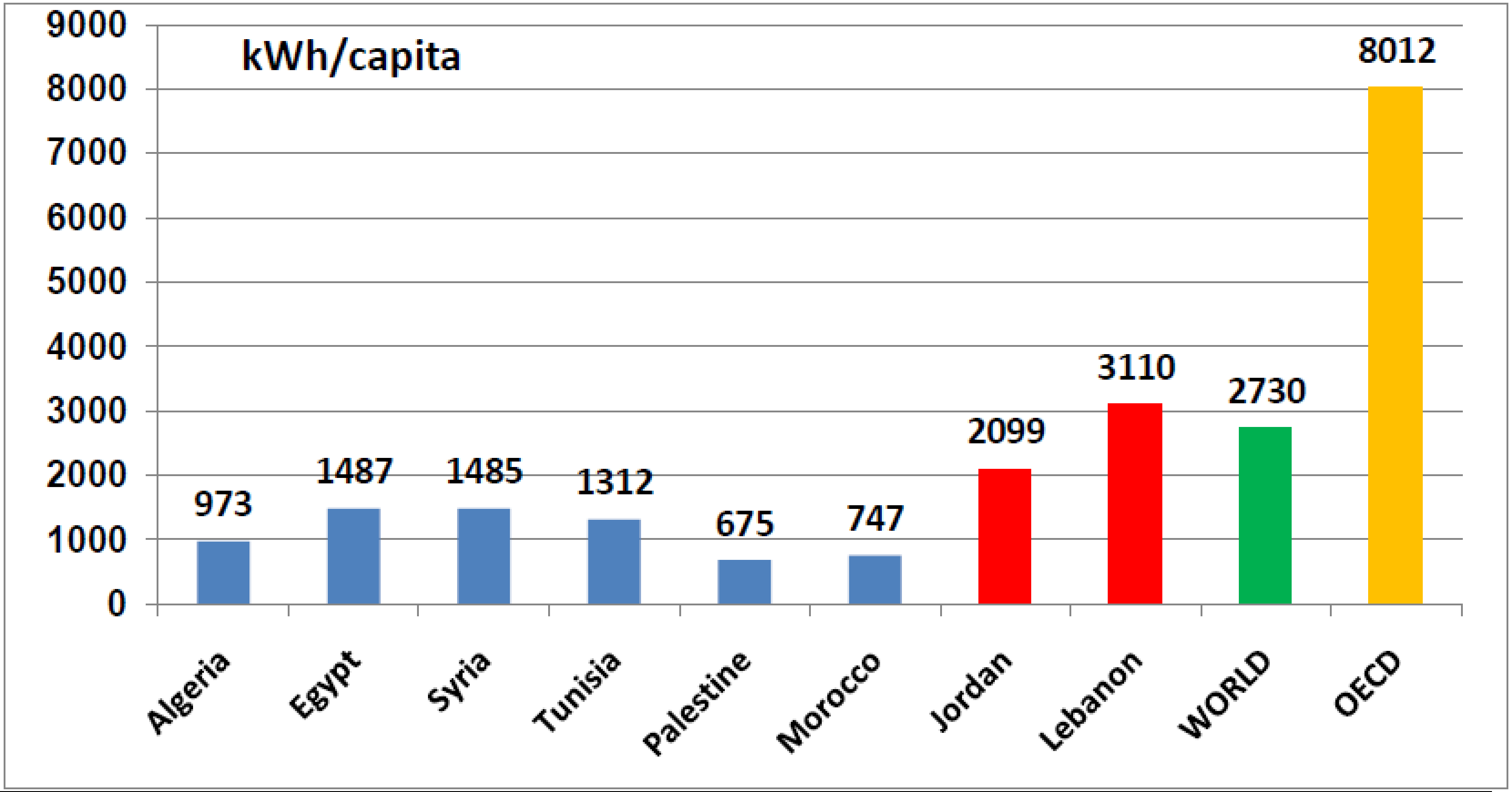
Primary Energy consumption per capita – (TOE/capita)



(Source: Key world energy statistics 2011 – Data 2009 - Palestine estimated)

Rafik Missaoui, Energy Efficiency Building Code Study
Final Report - October 2012 .
MED-ENEC.

Electricity consumption per capita ME-PCs (kWh/capita)



(Source: Key world energy statistics 2011 – Data 2009 – Palestine estimated)

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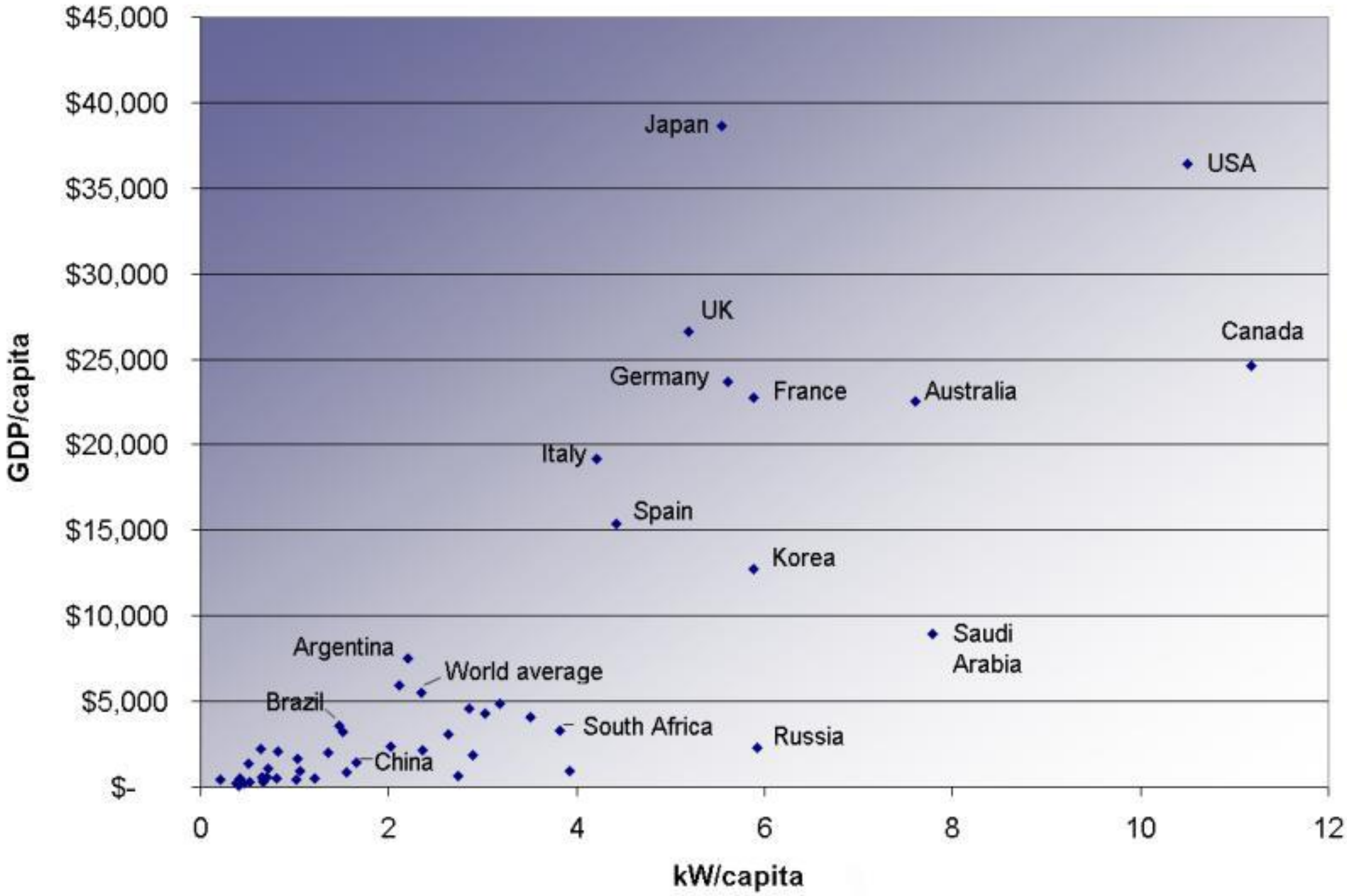
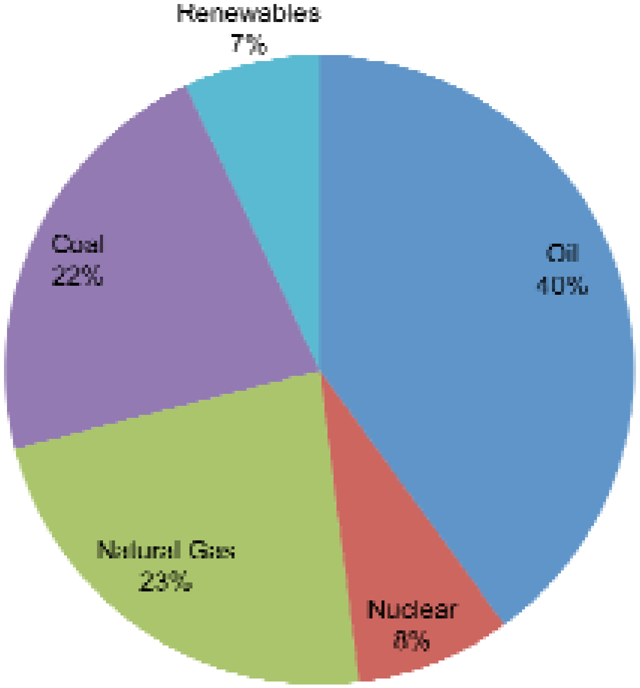
Energy consumption per capita vs. GNP per capita: the relation between wealth and energy



Energy Situation in Palestine

- Oil (40%) represented the largest share of Palestine's total primary energy supply (TPES), followed by natural gas (23%) and coal (22%)
- Renewable cover a significant share of Palestine's energy supply. The 7% share illustrated above includes 53% of biomass, 36% hydro, 5%
- wind, 5% geothermal energy and 1% solar energy.



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Energy demand and sources in Palestine

•Electricity: supplied from small diesel generators, Israeli utility company, and recently Gaza generators.
Grid connected: large cities = 85%
Diesel generators: villages = 10%
Without electricity: remote villages and communities = 5%
•Per capita electricity consumption: varies from city to another, and related to availability of electricity supply.
Average for West Bank (500kWh/yr.capita) compares with Jordan (1024kWh/yr.capita).
But Israel about (2000kWh/yr.capita).
•Gasoline and gas consumption in WB and Gaza.
•Other resources solar energy for water heating and woods for heating and cooling.

Costs of energy conversion

- Three types of costs are involved in the conversion process:
  - Energy cost (lose of energy).
  - Money cost.
  - Social cost (environment damage).

Energy cost

- Energy cost may constitute of:

1. Conversion losses:

e.g. coal electrical $\eta = 30 – 40\%$ Losses = 60 – 70%

wind energy electrical $\eta = 45\%$ or less

2. Energy expanded in manufacturing the fuel , e.g.:
   - Mining and extraction = 1.4% of total energy.
   - Liquefying and gasification of coal.
   - Transportation
   - Petroleum distillation.
3. Energy consumed in plant construction and equipment manufacturing.

Economic aspects of energy conversion

- Energy conversion processes are irreversible and losses are involved in the conversion processes.

Fuel combustion $\xrightarrow[\eta_b]{}$ thermal $\xrightarrow[\eta_{th}]{}$ mechanical $\xrightarrow[\eta_b]{}$ electrical

Wind energy $\xrightarrow[\eta_m]{}$ mechanical $\xrightarrow[\eta_e]{}$ electrical

External cost- Social /environment

- Some energy costs are not included in consumer utility or gas bills, nor are they paid for by the companies that produce or sell the energy.
- These include human health problems caused by air pollution from the burning of coal and oil; damage to land from coal mining and to miners from black lung disease; environmental degradation caused by global warming, acid rain, and water pollution; and national security costs.
- since the producers and the users of energy do not pay for these costs, society as a whole must pay for them.

Money Cost- Components

- The cost is divided into 2 main parts
  - ➢Fixed cost mainly first or initial investment, fixed regardless of production.
  - ➢Operation cost mainly operation and maintenance and fuel costs
- Operation cost = O&M + Fuel
- Total cost = fixed cost + operation cost

Fixed cost

- Fixed cost, initial costs, first year cost, or investment is the total amount of money used for the energy conversion system.
- It includes constructions and installation of the systems, the energy conversion system cost, commissioning and other costs that are employed before the operation of the system.

Fixed charges

- Fixed charges are independent of production (exist even with no production). Fixed charges consist of the following charges:
  - Interest or discount rate: cost of money use expressed as interest rate (e.g. i = 8%).
  - Taxes: such as land and properly taxes.
  - Insurance: against fire and shaft.
  - General salaries and general maintenance (e.g. guards, management, cleaning...).
  - Depreciation: part of revenue must be saved to cover the cost of replacing the equipment.

Depreciation

- Depreciation: part of revenue must be saved to cover the cost of replacing the equipment.
- Some reasons for replacing equipment are:
  - Life of enterprise and demand of its product ceases.
  - Life of equipment, because of wear and corrosion.
  - Inadequacy of equipment, due to increased demand.
  - Obsolescence of equipment due to new more efficient one.
- Allowing for depreciation methods include
  - *Straight-line method*: capital cost minus the salvage value is divided by lifetime of equipment. This amount is deduced annually from the income.
  - *Percentage method*: a fixed percentage of capital investment of the previous year (e.g. 5%).=

Depreciation

- Appraisal method: appraisal of value of equipment each year, the difference from previous year is the annual depreciation. It is not often applied.
- *Unit method*: annual depreciation equals to capital fund divided by hours of lifetime and multiplied by annual working hours.
- *Sinking fund method*: annual uniform deductions from income for depreciation is reinvested at constant rate and will accumulate to the capital value of enterprise at the end of its life time or accumulates to value needed to replace equipment.

Sinking fund

- Let A: annual contribution to sinking fund.

  S: sinking fund required to replace equipment.

  y: number of annual contribution.

  i: interest rate.

  n: useful life of equipment.

$$A = S * i / \left[\left(1 + \frac{i}{y} \right)^{ny} - 1 \right]$$

The fixed annual charges rate

Fixed annual charge rate	**% of fixed cost**
Interest	5-8
Taxes	2-5
Insurance	0.1-0.3
Depreciation	1-5
FCR	7-18

$$FCR = \left[i + \frac{i}{(1+i)^n - 1} + insurance + taxes \right]$$

i : interest rate.

n: lifetime.

Present & future worth

- Remember the relationship between future and percent value as:

  $S_{future} = S_{present}(1+i/y)^{ny}$

  i : interest rate.

  n: lifetime

  y: # of annual contributions

- Present worth

  PWF is calculated as; $PWF = 1/(1+i/y)^{ny}$

Operation or production cost

Operation or production cost is a function of amount of produced energy.

It consists of:

- Fuel cost: largest portion of the operating cost, fuel may be sold per unit mass, volume or energy, to compute fuel cost as $/energy may use:

  Annual fuel cost = (unit fuel cost)*(m_{fuel}).

  m_{fuel} = annual generated electrical energy/ HHV η_{th}

- Maintenance: repair, inspection, cleaning, ….
- Supervision and labor: total salaries, for all labor.
- Supplies: e.g. lubricating oil, water, utilities, office supplies..etc.
- Operating taxes: e.g. income taxes, social security, and unemployment.

Maintenance cost

- To calculate the cost of maintenance per unit energy, divide the annual maintenance cost by the annual energy production.
- Annual generated electrical energy is given as,

  E = rated power * load factor * hours of year

Note: load factor = plant factor

Economic assessment methods

- Annual cost
- Unit energy cost
- Payback period
- Return on investment
- Present worth
- Life cycle cost
- Life cycle savings

Annual cost

- Annual cost consists of the operation annual cost and the fixed charges of the initial or capital cost.
- The annual contribution of the capital cost can be estimated using the fixed charge rate FCR.
- Hence;

Annual cost = Annual Operating Cost + Capital cost * FCR

$$FCR = \left[i + \frac{i}{(1+i)^n - 1} + insurance + taxes\right]$$

i : interest rate.

n: lifetime.

Energy unit cost

- Cost per unit energy can be calculate based on the annual operating cost, the fixed charge rate, capital cost and the annual generated energy using the following equation:

$$COE = \frac{FCR * CapitalCost + AnnualOperationCost}{AnnualGenerateEnergy}$$

- Where COE: cost of unit energy $/kWh, FCR is the fixed charge rate, and annual generated energy in kWh.

E = (Rated power)(load factor)(8760 hr/yr)

Energy prices, Palestine

Consumer Energy Prices in Palestine (2008

Electricity	0.09 – 0.13 €/kWh
Gasoline	0.92 €/litre
Diesel	0.72 €/litre
Heavy fuel oil	0.3 €/kg
Kerosene	0.72 €/litre
Firewood	95 €/tonne

Table2 Average tariffs for electricity by type of consumers and regions

Distribution Utility	Household Price €/kWh	Commercial Price €/kWh	Industrial Price €/kWh
Municipality of Nablus	0.1244	0.1304	0.1098
Municipality of Jenin	0.1128	0.1097	0.1097
Municipality of Qalqilya	0.0810	0.0808	0.0790
Municipality of Hebron	0.0972	0.0972	0.0868
South Electrical Comp.	0.1008	0.0878	0.0800
Jerusalem District EC	0.0920	0.1062	0.0950
Gaza Electrical Comp.	0.0755	0.0762	0.0760

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Simple Payback period

- Payback period is the time required for the annual savings to pay for the added investment or the capital, and is given by the equation below.

Payback period = additional investment / annual savings

Example: Heating Alternatives

- Consider two heating alternatives A and B as shown in table below. Annual heating load is 100MJ, fixed charges is 18%.
- All costs are given then compared for the two options

Cost item	Option A $	Option B $
First cost (investment)	10000	7000
Annual fuel cost	1000	1500
Annual savings	1500-1000=500	
Additional investment	10000-7000=3000	
Payback period	3000/500=6 years	
Annual total cost	2800	2760
Unit energy cost	2800/100=28 $/MJ	27.6$/MJ

End of Introduction chapter