INTRODUCING RENEWABLE ENERGY

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UCLA

LECTURE OUTLINE

- ***Class Orientation***
  - *Introduction to Instructor*
  - *Course Overview & Objectives*
  - *Assignments & Grading*
  - *Course Schedule & Topics*
- ***Global Energy Use***
- ***Fossil Fuels and Climate Change***
- ***Definitions and Units***

Course Overview and Objectives

- We examine the issues involved in the thermodynamics, design, and operation of three main systems: solar, biomass, and hydro-power.

- We also discuss the integration of various clean energy sources and their economics.

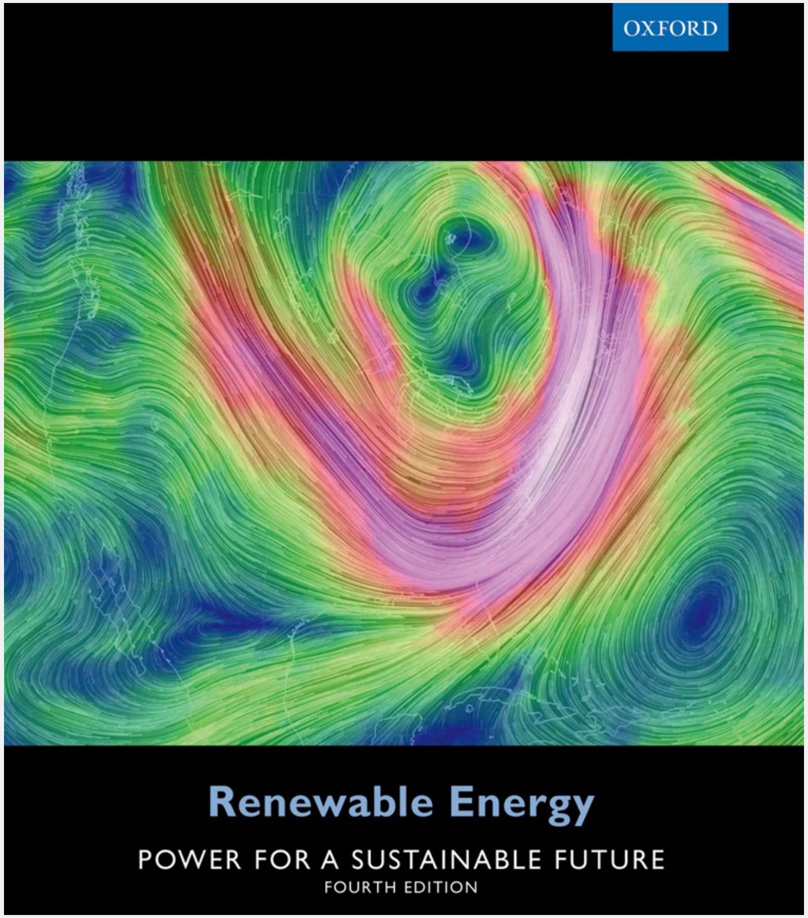
At the completion of this course you will be able to:

- • Understand the principles of operation of several clean energy technologies.
- • Analyze the "system" aspects of clean energy technologies.
- • Realize the technical and economic challenges of each system.
- • Learn the fundamental thermodynamics principles of energy conversion.

Required Textbook

1. Peake, Stephen. Renewable Energy: Power for a Sustainable Future, Fourth Edition, 2018, Oxford University Press, EISBN 978-0-19-253777-5. 2012.

2. Online lesson content: All other materials are presented online through our course website.



Assignments

- **Midterm**: An open-book midterm exam will be held midway in the course.
- **Homework Assignments**: There will be homework assignments throughout the course. They will cover material from multiple lessons per assignment.
- **Final Assignment**: After the last lecture, you will submit a 500-word original research assignment on one of the renewable energy topics.

Grading

Grade Category	Percent of the Grade
Homework	30%
Midterm	20%
Final Research Abstract Assignment	50%

Table 1: Grading Scheme

Letter Grade	Percentage
A+	>95%
A	90-95%
A-	85-90%
B+	80-85%
B	75-80%
B-	70-75%
C	$< 70\%$

Table 2: Letter grade percentages

Course Schedule

Week 1

- Class orientation.
- Global energy use.
- Fossil fuels and climate change.
- Overview of renewable energy sources.
- Reading Assignment: Chapter 1 - Introducing Renewable Energy.

Week 2

- Energy forms and energy conservation principles.
- Basic units and definitions.
- Work and examples on work.
- Potential and kinetic energy.
- First law of thermodynamics.
- Examples on the first law.

Week 3

- Second law of thermodynamics.
- Fuels & combustion.
- Heat engines.
- Heat pumps.
- Efficiency and Coefficient of Performance.
- Reading Assignment: Chapter 2 - Thermodynamics, heat engines, and heat pumps.

Week 4

- Thermodynamic cycles for renewable energy.
- Rankine Cycle.
- Organic Rankine Cycle.
- Reading Assignment: - Thermodynamic cycles for renewable energy.

Week 5

- Thermodynamic cycles for renewable energy.
- Solar Rankine Cycle.
- Geothermal Cycles.
- Reading Assignment: - Thermodynamic cycles for renewable energy.

Week 6

- Solar Thermal Energy
- Availability of solar energy
- Low-temperature applications.
- Reading Assignment: Chapter 3 - Solar-Thermal Energy.

Week 7

- Active versus passive heating.
- Electricity generation fro solar thermal sources.
- Economics & environmental impact.
- Solar photovoltaics basic principles

Week 8

- Polycrystalline and thin film photovolatics.
- PV grid-connected systems & integration.
- Environmental impact & economics.
- Reading Assignment: Chapter 4 - Solar Photovoltaics.

Week 9

- Bioenergy sources
- Combustion of solid biomass.
- Fuel production (gaseous and liquid).
- Environmental impact & economics.
- Reading Assignment: Chapter 5 - Bioenergy.

Week 10

- History of water power.
- Hydro resources.
- Types of hydroelectric plants.
- Turbines.
- Integration
- Environmental impact & economics.
- Reading Assignment: Chapter 6- Hydroelectricity.

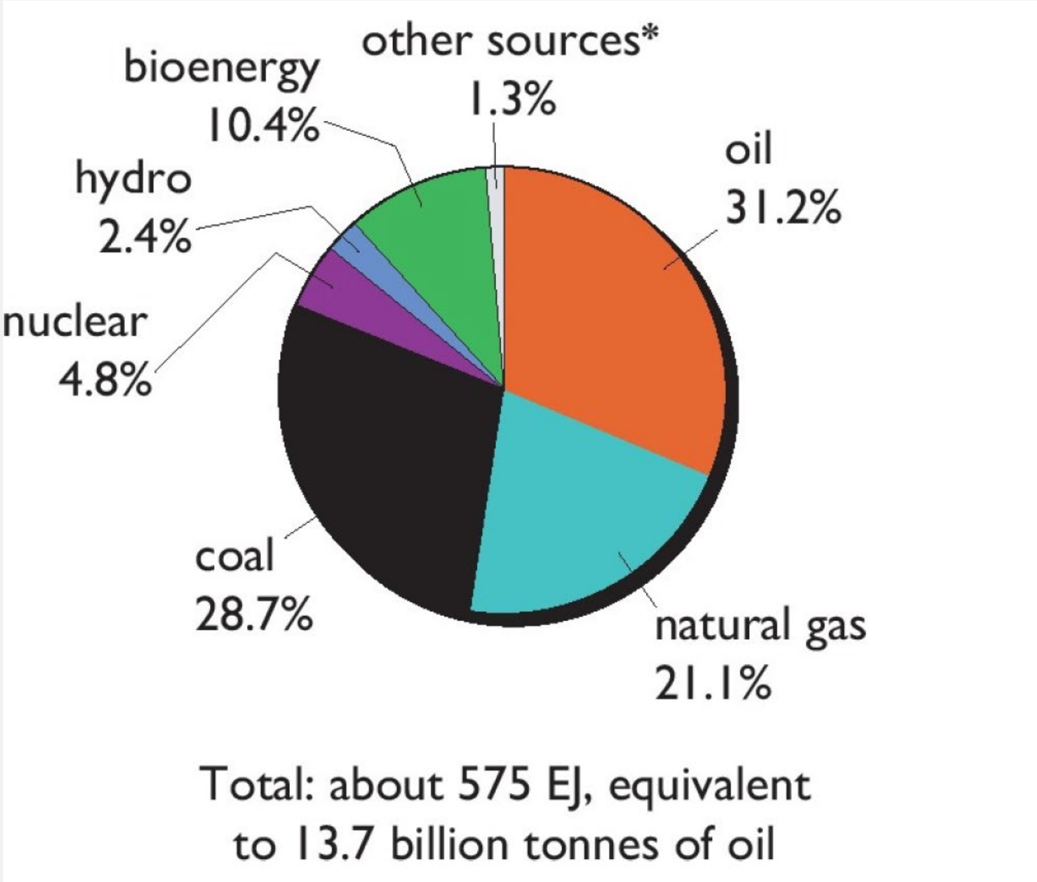
Global Energy Use

Energy Forms

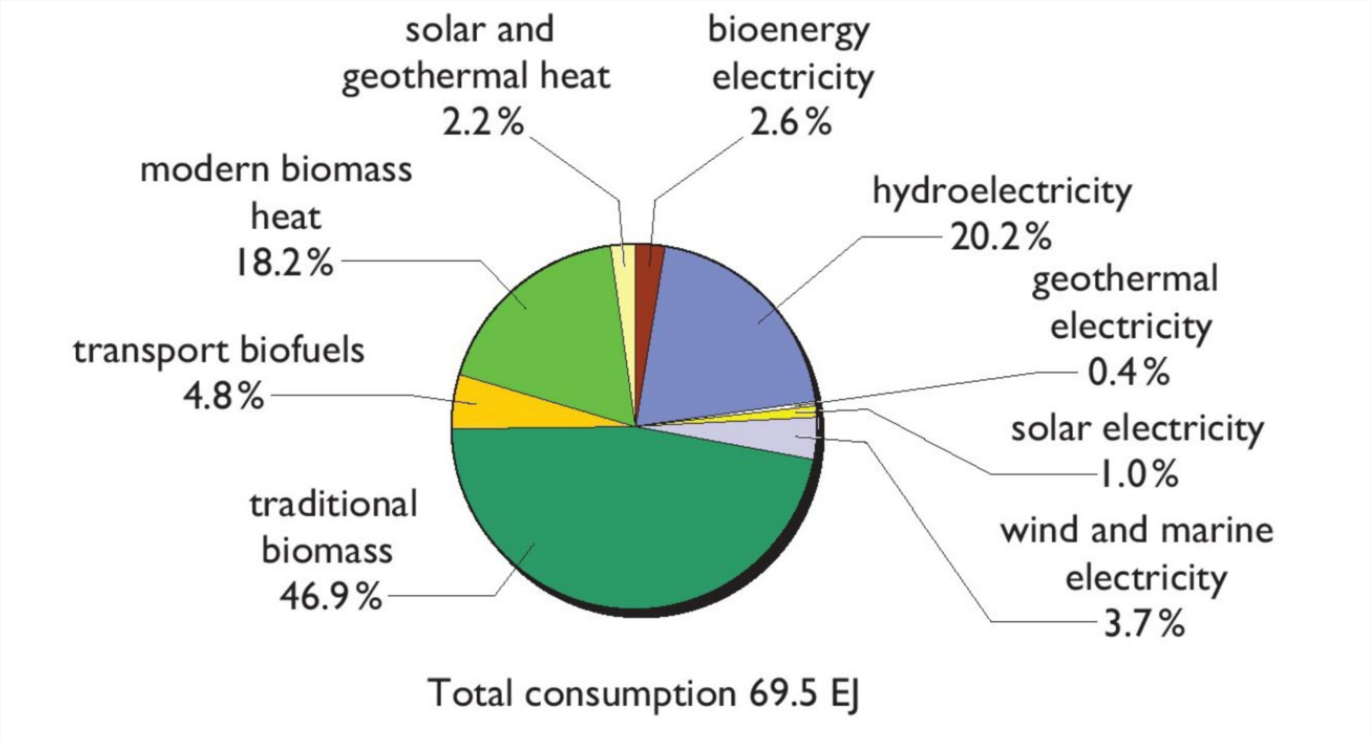
- The **primary energy :** The energy released when the fuel is burned.
- The **delivered energy :** The amount of electricity reaching the consumer, after conversion losses in the power station and transmission losses in the electricity grid,. This is what the consumer actually receives (and pays for).
- The **useful energy:** After further losses in the water tank and pipes, a final quantity that comes out of the hot tap.
- The world total annual consumption of all forms of primary energy increased more than tenfold during the twentieth century.
- By the year 2014 had reached an estimated 575 EJ (exajoules), or about 13 700 million tonnes of oil equivalent (Mtoe).

World Energy Consumption (2014)

Exa-Joule=10^{18} Joules

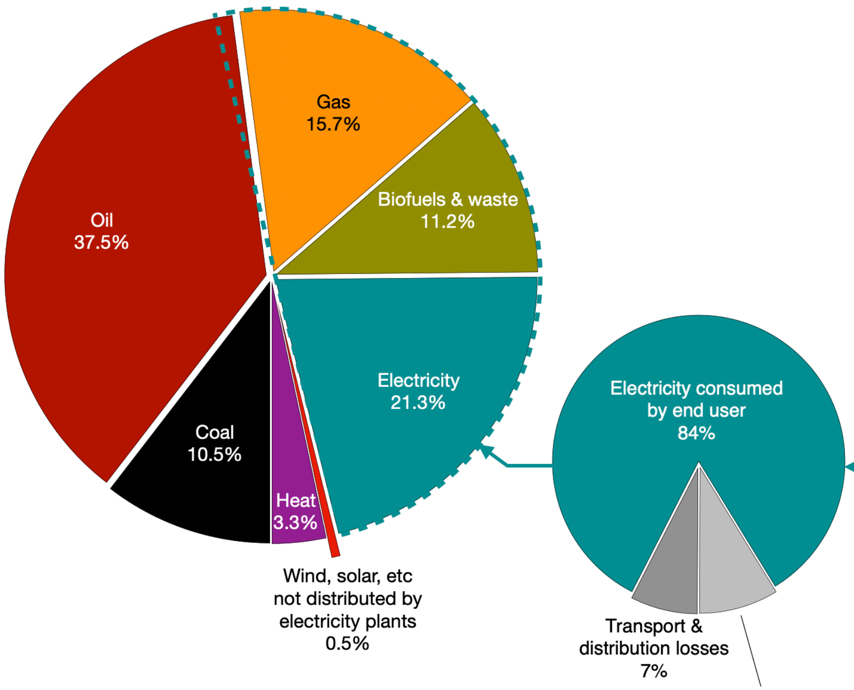


World Renewable Energy Consumption



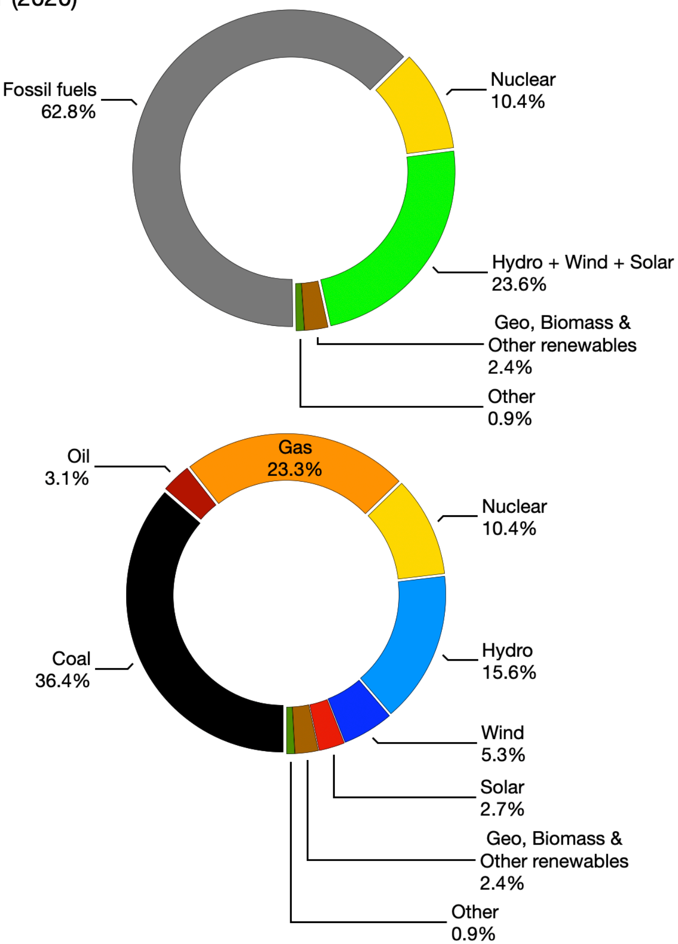
Current World Energy Consumption

World total final consumption minus non energy use (final energy)
Energy consumed by end-user
Year 2018
Data: IEA(2020)

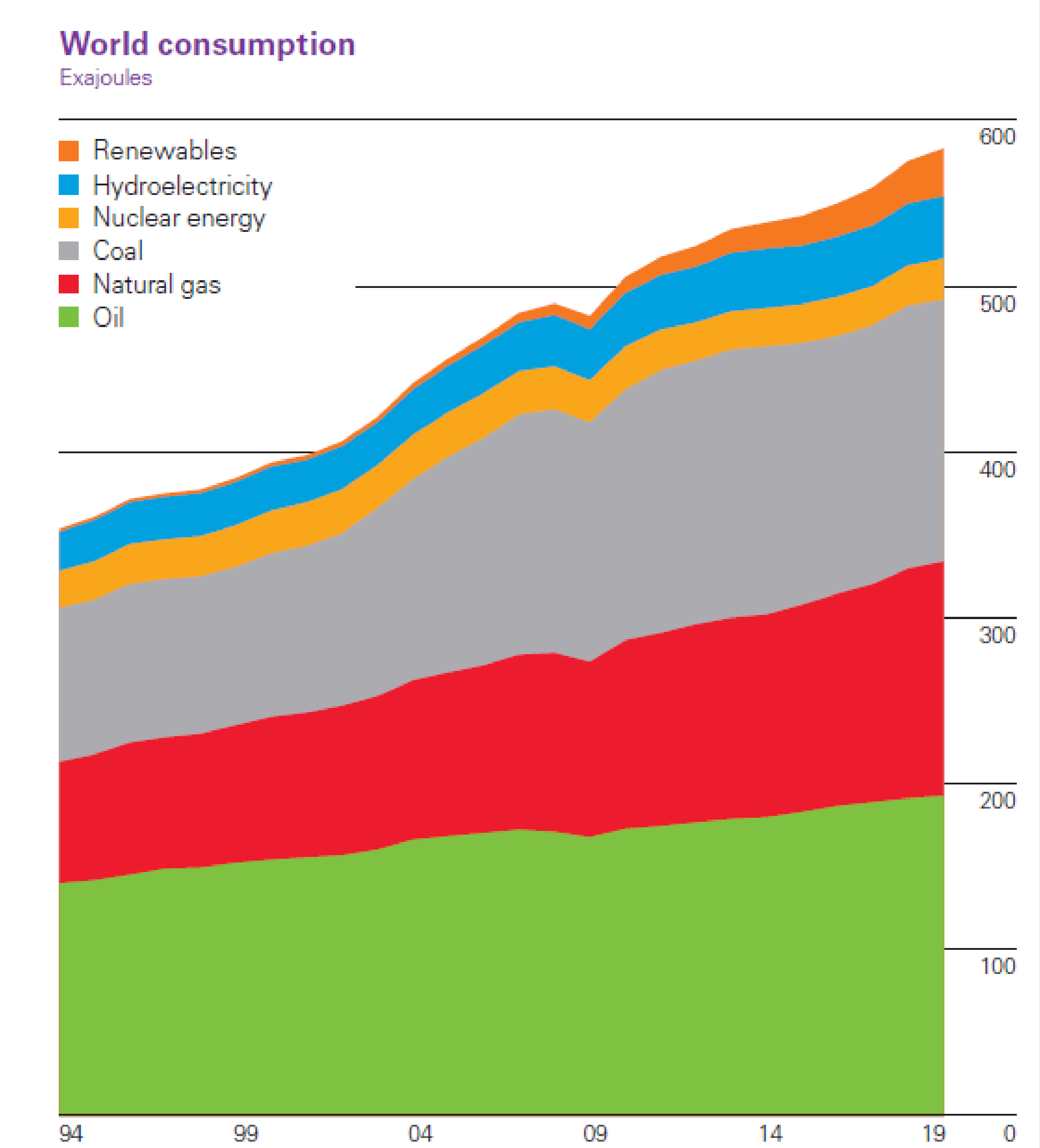


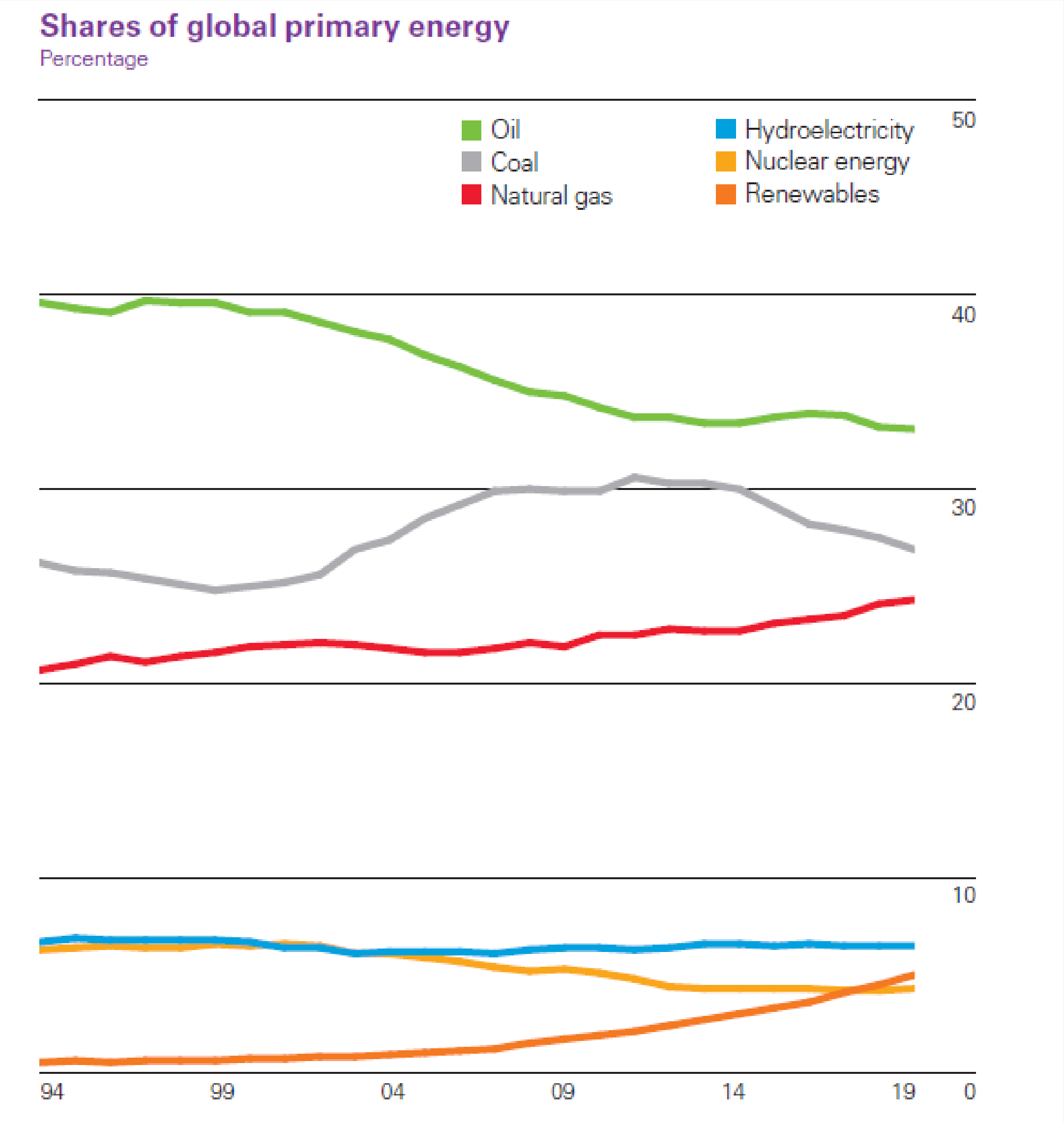
Hydrogen (H_2) consumption was negligible and too small to show. According to https://www.iea.org/fuels-and-technologies/hydrogen, H_2 production in 2019 (most recent year of data) was 0.36Mt (consumption data unavailable). At the maximum rated energy content of 142 MJ/kg, this was equivalent to 0.014% of world total final energy.

World electricity generation
Year 2019
Data: BP(2020)



Growth of World Energy Consumption





Shares of global primary energy
Percentage
Oil
Coal
Natural gas
Hydroelectricity
Nuclear energy
Renewables
50
40
30
20
10
0
94
99
04
09
14
19

World Energy Consumption (2014)

- The world population in 2014 was some 7.2 billion.
- The annual average energy consumption per person was about 80 GJ (gigajoules).
- This equivalent to 6 litres of oil per day per person.

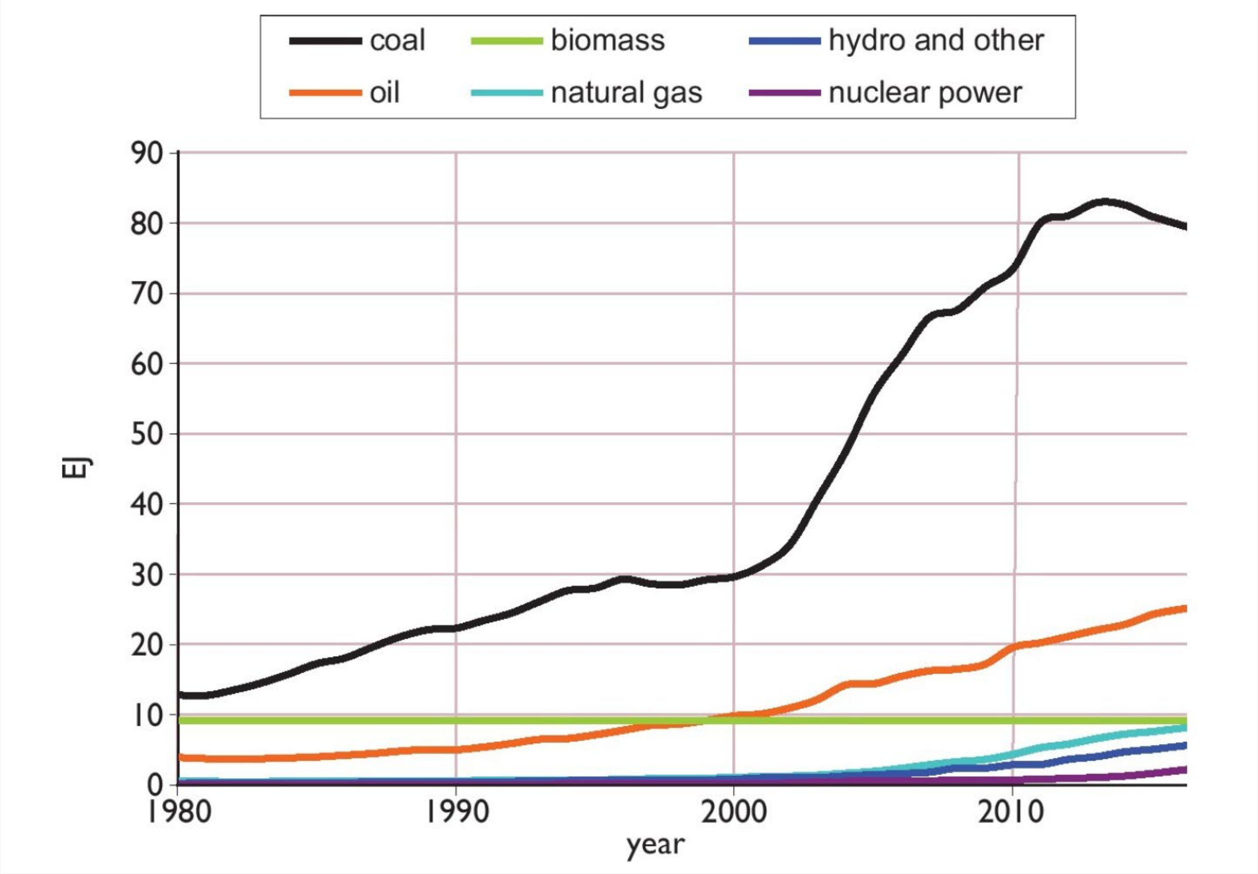
Table 1.2 Electricity generation by fuel

	Coal	Oil	Natural gas	Nuclear	Hydro	Wind and other sources*
UK – 2015	21%	0%	29%	25%	2%	22%
USA – 2015	33%	1%	33%	20%	6%	7%
China – 2014	72%	0%	2%	2%	19%	4%
World – 2014	41%	4%	22%	11%	16%	6%

How long will fossil fuels last?

- World coal reserves could last for over 150 years.
- Oil and natural gas reserves could last for approximately 50 years
- Concerns about climate change and the urgent need to reduce CO_2 emissions from fossil fuel combustion mean that most of the world's proven fossil fuel reserves will have to stay in the ground

Energy in China



Energy in China

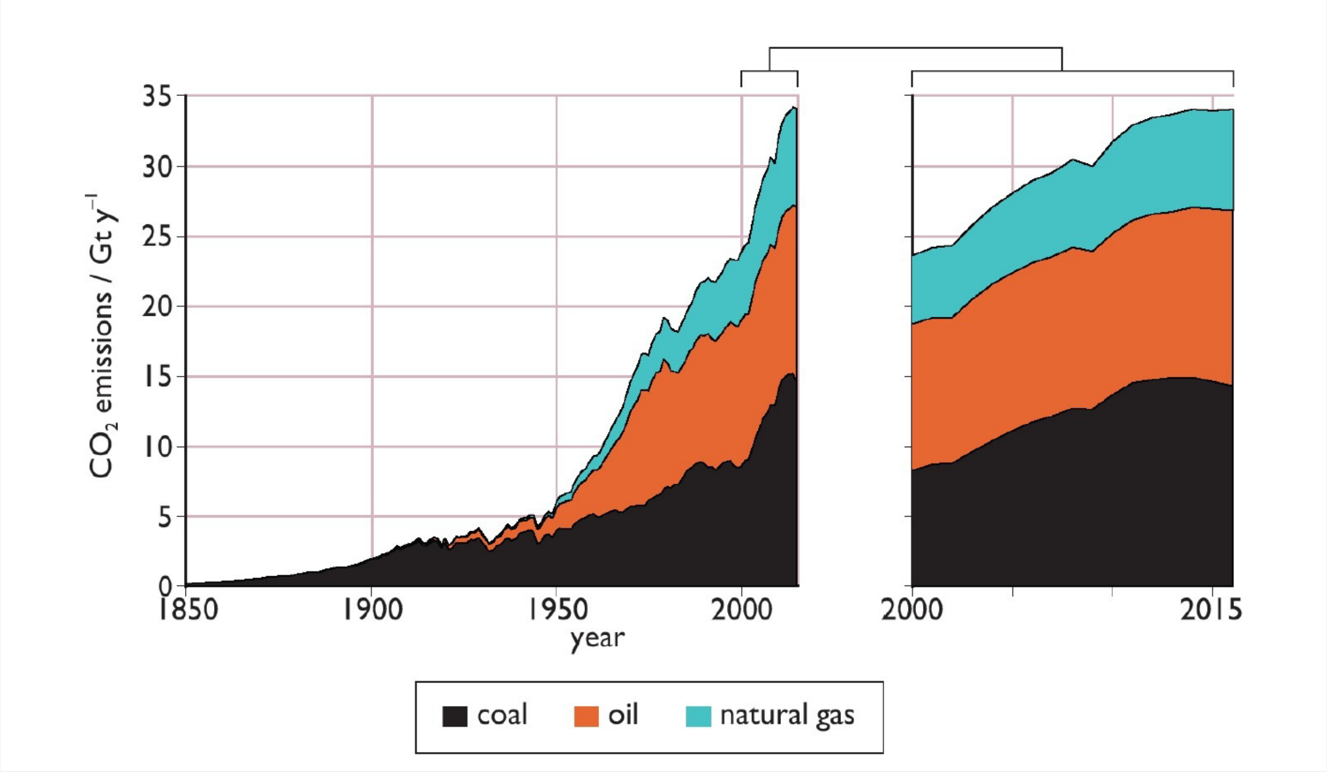
- China has invested heavily in hydropower, which in 2016 made up 19% of its electricity supply with enormous projects such as the Three Gorges Dam.
- It is also investing heavily in wind turbines. In 2016, China had an estimated 149 GW of installed wind power. This supplied about 4% of China’s electricity supply.
- China is also the world’s largest installer of solar PV electricity generation. In 2016 it had approximately 78 GW of PV capacity. The country also accounts for 70% of the world’s sales of solar water heaters.
- Overall, in 2016 China was the world leader in both renewable electricity generating capacity and in investment in renewable energy technologies.

Fossil fuels and climate change

- The surface temperature of the Earth establishes itself at an equilibrium level.
- The incoming energy from the Sun balances the outgoing infrared energy re-radiated from the surface back into space.
- If the Earth had no atmosphere its surface temperature would be –18 °C;
- Its atmosphere, which includes 'greenhouse gases' – principally, water vapor, carbon dioxide, and methane – acts like the panes of a greenhouse, allowing solar radiation to enter but inhibiting the outflow of longwave infrared radiation.
- The natural 'greenhouse effect' that these gases cause is essential in maintaining the Earth's average surface temperature at a level suitable for life, at around 15 °C.

CO2 emissions are causing global warming

CO_2 in the atmosphere has risen from 280 parts per million (ppm) to 400 ppm in 2016 and is currently rising at around 3 ppm per year.



CO2 emissions are causing global worming

- The global surface temperature in 2016, the warmest year on record, was 0.99 °C above the 1951-1980 average.
- The Earth's surface temperature could rise by around 4 °C by the end of the twenty-first century. Such rises would probably be associated with an increased frequency of climatic extremes,
- such as floods or droughts, and serious disruptions to agriculture and natural ecosystems.
- The world's oceans could mean that sea levels would rise by around 0.5 m by the end of the century.
- Following the 21st International Meeting (COP 21) held in Paris in late 2015, a total of 195 countries committed to curbing their greenhouse gas emissions.
- They agreed to hold the increase in the global average temperature to well below 2 °C above preindustrial level.
- A 2 °C target will mean limiting the atmospheric concentration of CO_2 to 450 ppm

Renewable Energy Overview

What is Renewable Energy?

Energy that doesn't run out!

- Energy that can be used without reducing its availability in the future.
- Natural forces (heat, radiation, motion)
- Chemical energy from biomass (biofuels)
- Biomass is included because it can be replaced in a human time-frame.

Renewable Energy Sources

- Hydropower
- Marine energy
- Solar energy
- Wind energy
- Geothermal
- Bioenergy

Hydropower

Water drives turbines to make electricity. Two types:

- Run of river
- Storage (reservoir)

Characteristics:

- High investment, low cost
- Easy to control
- Social/environmental issues
- Can be used for storage

Marine Energy

Energy from oceans (mechanical, thermal, chemical energy). Five main types:

- Tidal energy
- Ocean energy
- Wave energy
- Ocean Thermal Energy Conversion (OTEC)
- Salinity gradient power

Still largely at development stage, but with significant potential.

Marine Energy

Tidal energy:

- Mechanical power used for electricity generation
- Used in locations with large tidal range
- Similar to hydropower, but more for baseload power

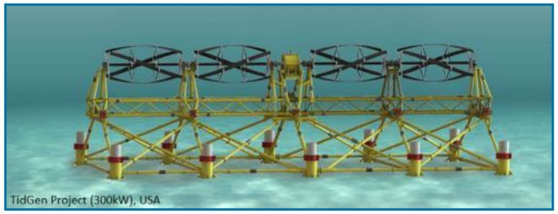
Some well-established facilities, other new ones being developed

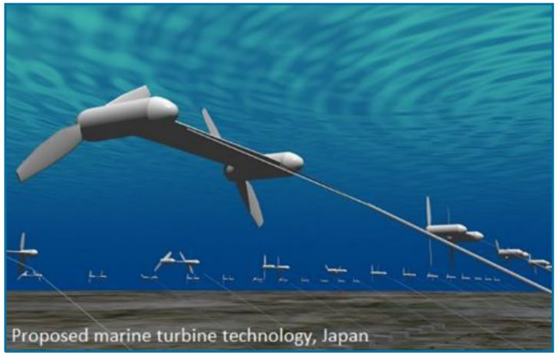
Marine Energy

Ocean energy:

- Mechanical power used for electricity generation
- Turbines of many different designs
- Baseload power, without major construction of dams and barriers

Pilot-scale projects under development





Marine Energy

Wave energy:

- Mechanical power used for electricity generation
- Many different designs, generally low impact
- Variable resource

Pilot-scale projects under development

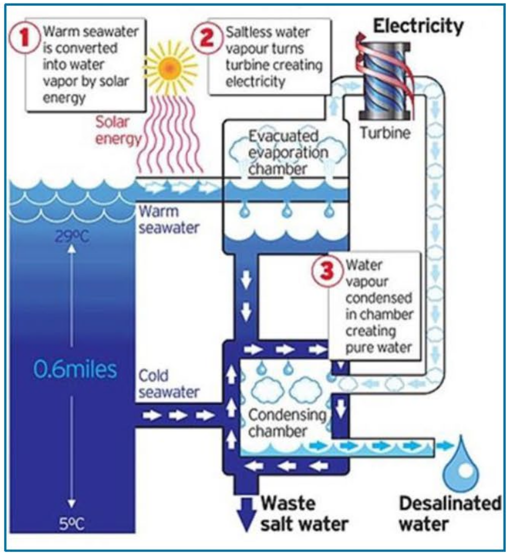
Powerbuoy (150 kW), USA

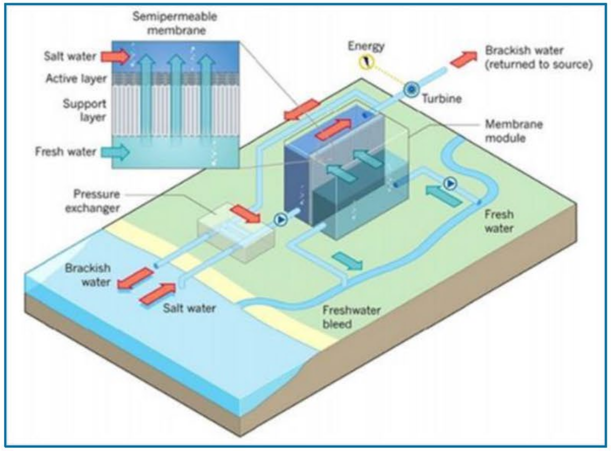

Pelamis wave energy converters (750 kW)

Marine Energy

Ocean Thermal Energy Conversion (OTEC):

- Power generation from temperature difference between surface and deep ocean





Salinity gradient power:

- Power generation from difference in salinity between sea water and fresh water

Wind Energy

Wind drives turbines to make electricity. Two types:

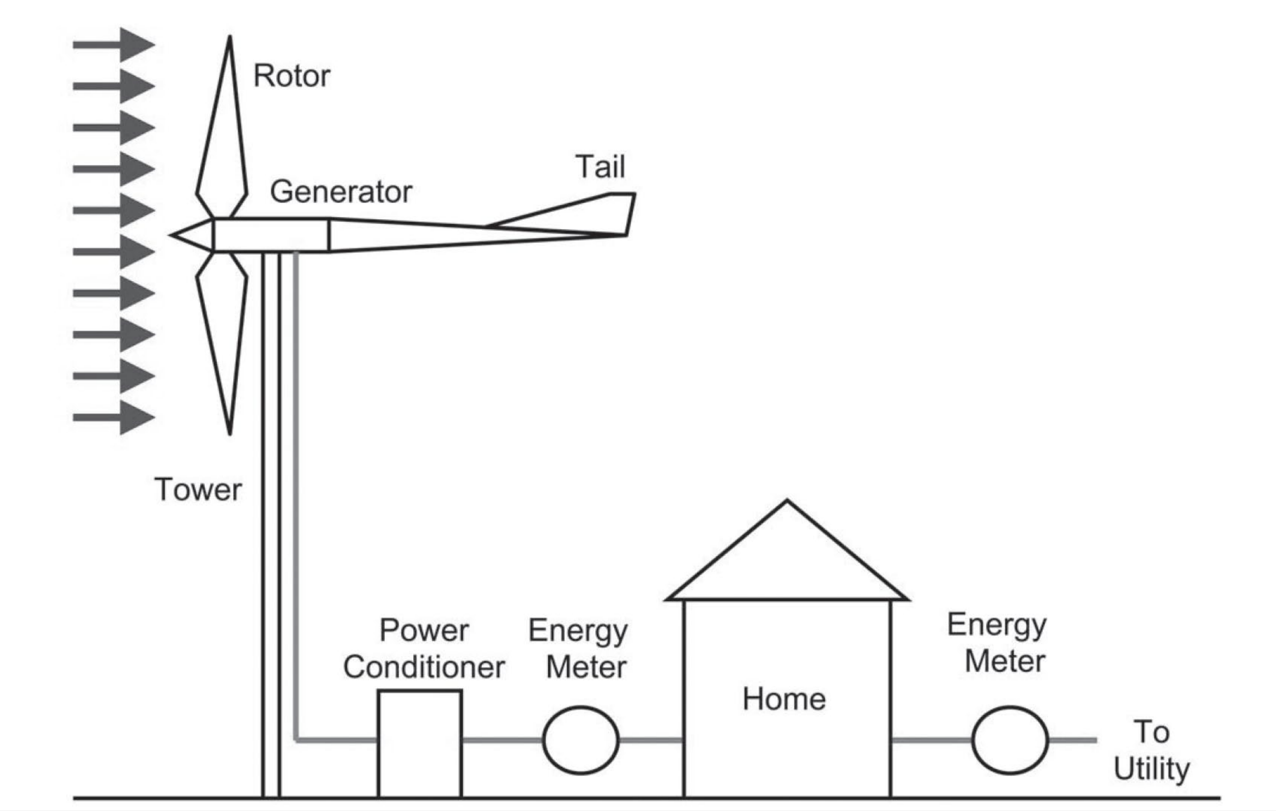
- Onshore
- Offshore

Characteristics:

- Low cost (onshore)
- Variable resource
- Some environmental issues
- Scalable

Wind Energy

Grid-connected residential wind energy system



Solar Energy

Energy from the sun converted directly into electricity or used as thermal (heat) energy:

- Solar photovoltaic (Solar PV)
- Solar thermal:
  - Concentrated Solar Power (CSP)
  - Other solar energy

Third largest source of electricity from renewables and developing rapidly.

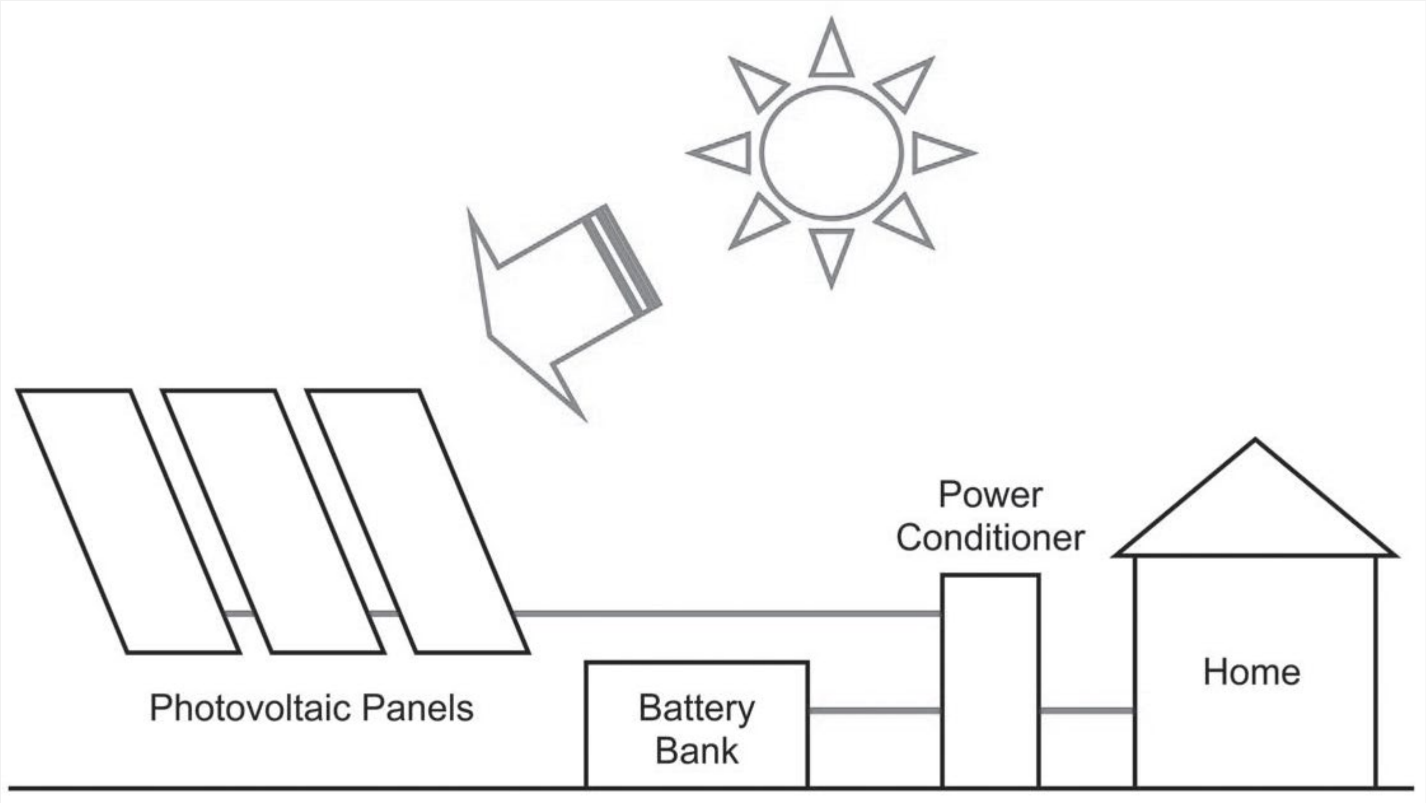
Solar Energy

Solar photovoltaic (PV):

- Light converted directly into electricity
- Rapidly falling costs
- Variable but abundant resource, with few issues
- Scalable (good for off-grid)

Growing rapidly in many countries.

Residential Photovoltaic System

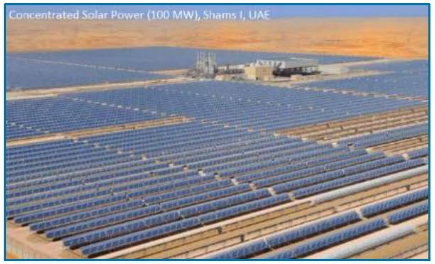


Solar Energy

Concentrated Solar Power:

- Focused sunlight heats a fluid that drives a turbine
- Various designs
- Variable resource, but heat can be stored
- Large-scale, can produce electricity and heat

Growing in countries with good solar resource.



Concentrated Solar Power (100 MW), Shams I, UAE

Concentrated Solar Power (1.4 MW), Puerto Errado, Spain

Concentrated Solar Power (126 MW), Ivanpah, USA

Solar Energy

Other solar energy:

- Active heating, using collectors, fans and pumps
- Excludes passive heating
- Used for heat production
- Wide variety of devices
- Can be large (Concentrated Solar Thermal)

At present, most active solar systems are water heaters.

Geothermal Energy

- Steam and/or hot water taken from wells and used to produce electricity and heat
- Generally, large-scale, cost-effective and used for baseload power production
- Viable geothermal resources are quite limited


Geothermal wells, Olkaria, Kenya


Geothermal power plant (185 MW), Olkaria I, Kenya

Bioenergy

Bioenergy is energy derived from non-fossil materials of biological origin. There are three main types:

- Solid biofuels and renewable waste
- Biogas (gaseous biofuels)
- Liquid biofuels

Bioenergy is produced from the combustion of biofuels and has many different uses (heat, electricity, transport).

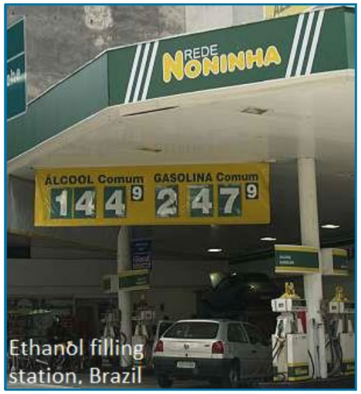
Bioenergy

Liquid biofuels:

- Biogasoline and biodiesel
- Conventional and advanced
- Aviation fuel, others

Characteristics:

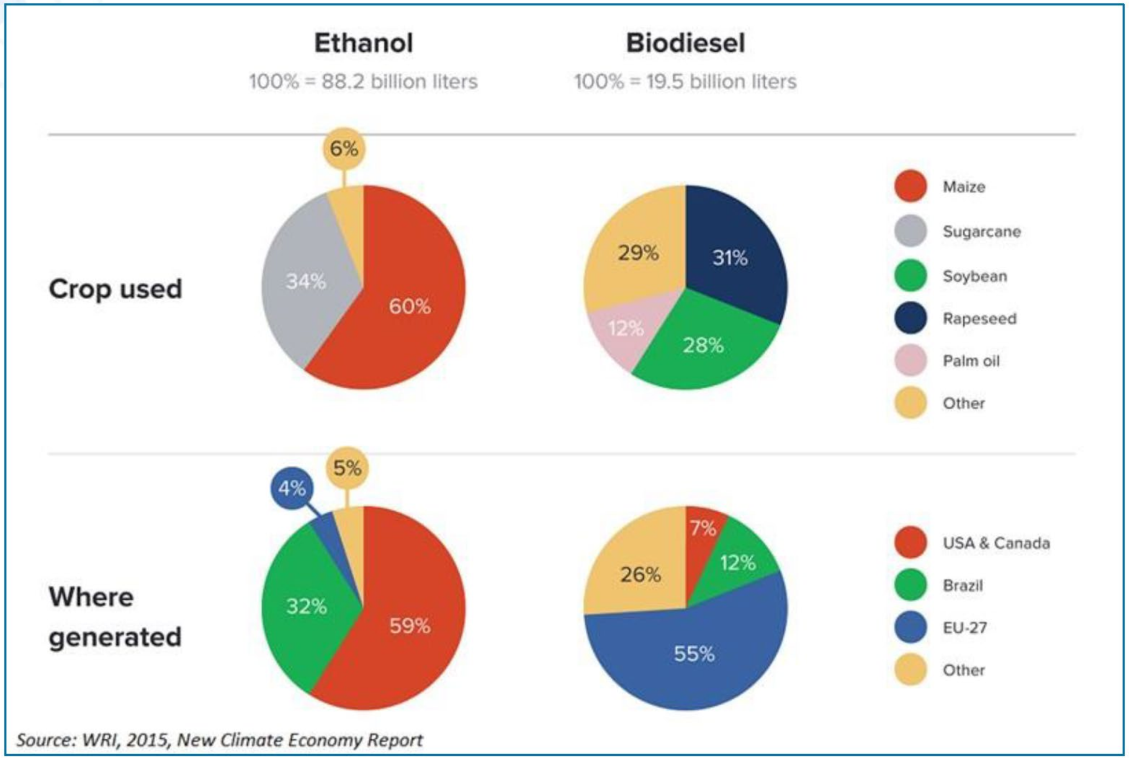
- Made using thermal, chemical and biological processes
- Used mainly for transport
- Competition for feedstocks
- Energy efficiency



Ethanol filling station, Brazil

Aviation biofuel

Bioenergy



Most liquid biofuels are made from food crops

Bioenergy

Biogas:

- Landfill gas
- Sewage sludge gas
- Others from fermentation
- Gas from thermal processes

Characteristics:

- Used for electricity and heat
- Relatively cheap
- Good environmental impact
- Scalable (good for off-grid)

Bioenergy

Solid biofuels and renewable waste:

- Biofuel crops
- Waste materials
- Processed solid biofuels

Characteristics:

- Used for electricity and heat
- Relatively cheap and most common renewable energy
- Some social, economic and environmental issues

Other Renewable Energy

Heat pumps:

- Ground source
- Water source
- Air source

Pipes for ground source heat pump

Characteristics:

- Used for heat production or both heating and cooling. Works like an air conditioner.
- High investment, but low running cost

Basic Physics

Definitions

- **Energy (E)** is basically the '**capacity to do work**'. Its unit is Joules (J).
- **Power (P)** is the *rate* of use of energy and commonly has units of the watt (W) or kilowatt (kW). 1 W= 1 J/s.
- The **efficiency** of an energy process is the ratio of its output energy to its input.
- **The capacity factor** of an electricity generation plant is the ratio of its actual output to what it might produce if it could run at full power all of the time.

Definitions

Renewable energy sources are essentially those that are continuously replenished. Most are derived from energy supplied by the Sun.

Direct solar energy uses include **solar thermal water heating**, **passive solar heating** of buildings, and electricity generation using **solar photovoltaics (PV)** or **concentrating solar power (CSP)**.

Indirect solar energy uses include **hydropower**, **wind power** and **wave power**, both derived from the world's air currents, and **bioenergy**, derived from plant materials.

Non-solar renewables include **tidal energy**, **deep geothermal energy**, and **heat gains from heat pumps**.

Energy Forms

- **Kinetic**, that of a mass in motion. **Heat energy** can be considered as a form of this
- **Gravitational** or **potential**, that acquired by a mass moving against gravity
- **Electrical**, which may involve currents flowing in wires but also includes
  - **electromagnetic energy**, waves travelling through space such as light, and
  - **chemical energy**, that of the chemical bonds within fuels
- **Nuclear** energy, energy derived from the fission of atoms.

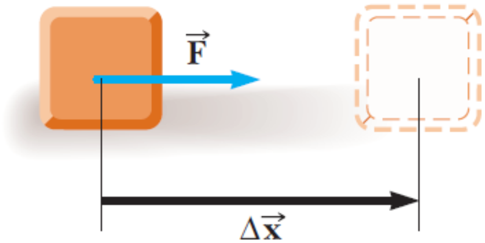
S.I. Units & Prefixes

Unit of energy = Joule =J = $kg.m^2/s^2$
Unit of power = Watt = J/s = $kg.m^2/s$
Unit of force = Newton=N= $kg.m/s^2$
Unit of pressure (or stress)=Pascal=Pa
=N/m^2= $kg/(m.s^2)$

Some Prefixes for Powers of Ten Used with "Metric" (SI and cgs) Units

Power	Prefix	Abbreviation
10^{-18}	atto-	a
10^{-15}	femto-	f
10^{-12}	pico-	p
10^{-9}	nano-	n
10^{-6}	micro-	μ
10^{-3}	milli-	m
10^{-2}	centi-	c
10^{-1}	deci-	d
10^{1}	deka-	da
10^{3}	kilo-	k
10^{6}	mega-	M
10^{9}	giga-	G
10^{12}	tera-	T
10^{15}	peta-	P
10^{18}	exa-	E

Work

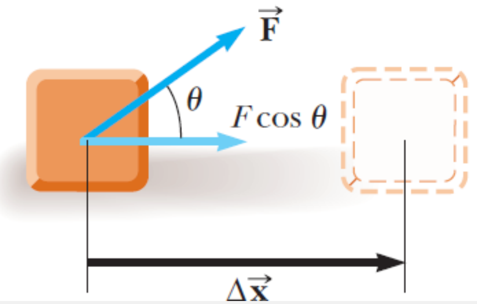


The work W done on an object by a constant force $\vec{\mathbf{F}}$ is given by

$$W = F\Delta x \qquad [5.1]$$

where F is the magnitude of the force, Δx is the magnitude of the displacement, and $\vec{\mathbf{F}}$ and $\Delta\vec{\mathbf{x}}$ point in the same direction.

SI unit: joule (J) = newton · meter = kg · m²/s²



The work W done on an object by a constant force $\vec{\mathbf{F}}$ is given by

$$W \equiv (F\cos\theta)\Delta x \qquad [5.2]$$

where F is the magnitude of the force, Δx is the magnitude of the object's displacement, and θ is the angle between the directions of $\vec{\mathbf{F}}$ and $\Delta\vec{\mathbf{x}}$.

SI unit: joule (J)

Kinetic Energy

The **kinetic energy** ***KE*** of an object of mass m moving with a speed v is defined by

$$KE \equiv \frac{1}{2}mv^2 \qquad \textbf{[5.5]}$$

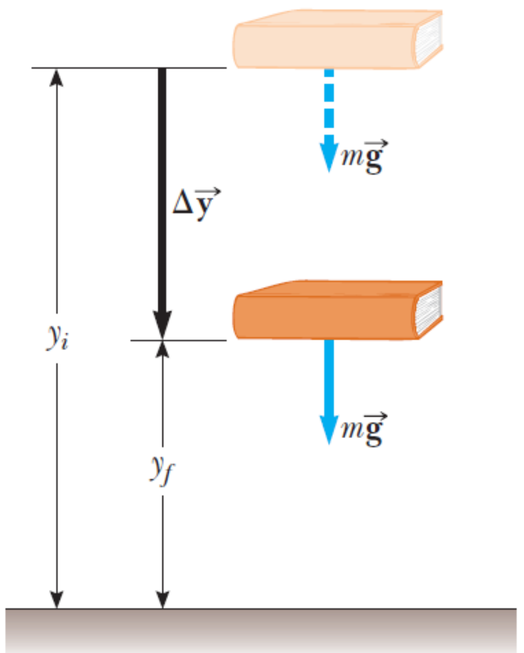
SI unit: joule (J) = kg · m²/s²

The net work done on an object is equal to the change in the object's kinetic energy:

$$W_{\text{net}} = KE_f - KE_i = \Delta KE \qquad \textbf{[5.6]}$$

where the change in the kinetic energy is due entirely to the object's change in speed.

Potential Energy



$$W_g = F\Delta y \cos\theta = mg(y_i - y_f)\cos 0^\circ = -mg(y_f - y_i)$$

The gravitational potential energy of a system consisting of the Earth and an object of mass m near the Earth's surface is given by

$$PE \equiv mgy \qquad \textbf{[5.10]}$$

where g is the acceleration of gravity and y is the vertical position of the mass relative the surface of Earth (or some other reference point).

SI unit: joule (J)

Gravity & Conservation of Mechanical Energy

In any isolated system of objects interacting only through conservative forces, the total mechanical energy $E = KE + PE$, of the system, remains the same at all times.

Problem A diver of mass m drops from a board 10.0 m above the water's surface, as in Figure 5.16. Neglect air resistance. **(a)** Use conservation of mechanical energy to find his speed 5.00 m above the water's surface. **(b)** Find his speed as he hits the water.

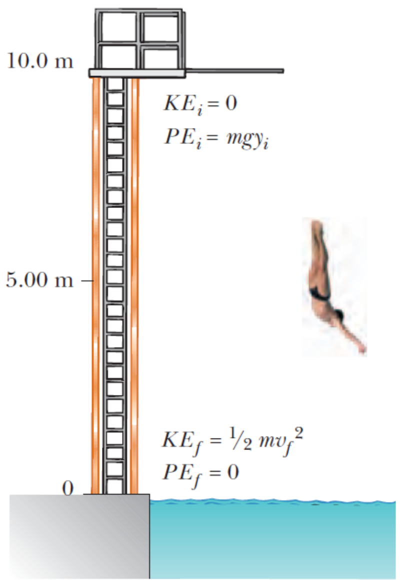


Figure 5.16 (Example 5.5) The zero of gravitational potential energy is taken to be at the water's surface.

Problem Solution

Solution

(a) Find the diver's speed halfway down, at $y = 5.00$ m.

Figure 5.16 (Example 5.5) The zero of gravitational potential energy is taken to be at the water's surface.

Step 3: we write the energy conservation equation and supply the proper terms:

$$KE_i + PE_i = KE_f + PE_f$$

$$\frac{1}{2}mv_i^2 + mgy_i = \frac{1}{2}mv_f^2 + mgy_f$$

Step 4: Substitute $v_i = 0$, cancel the mass m and solve for v_f:

$$0 + gy_i = \frac{1}{2}v_f^2 + gy_f$$

$$v_f = \sqrt{2g(y_i - y_f)} = \sqrt{2(9.80\text{ m/s}^2)(10.0\text{ m} - 5.00\text{ m})}$$

$$v_f = \boxed{9.90\text{ m/s}}$$

(b) Find the diver's speed at the water's surface, $y = 0$.

Use the same procedure as in part (a), taking $y_f = 0$:

$$0 + mgy_i = \frac{1}{2}mv_f^2 + 0$$

$$v_f = \sqrt{2gy_i} = \sqrt{2(9.80\text{ m/s}^2)(10.0\text{ m})} = \boxed{14.0\text{ m/s}}$$