Energy for generations

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12th edition

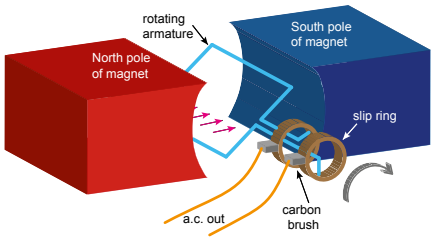
Generating renewable energy

What is energy?

We use the word ***energy*** in many different ways and are not too troubled about defining it. However, in physics, it has a specific and precise definition. To a scientist energy is the ability to do ***work***. 'Work' is defined as being done when a ***force*** acts on an object, ***accelerating*** it over a distance.

Power is then defined as the **rate** of doing work. For example, a car that travels a kilometre more quickly than another is more powerful i.e. it has used the same energy in a shorter interval of time.

There are many forms of energy including potential, kinetic, elastic, electric, magnetic, chemical, thermal and nuclear. The ***law of conservation of energy*** tells us that energy can neither be created nor destroyed, but it can be transformed from one type to another. The challenge is to develop ways of transforming energy that already exists into forms that are more useful.



By rotating the coil (armature) in a magnetic field an alternating current in generated

In this lesson we discuss some of the technologies used by the ESB to transform energy into the valuable product called ***electricity***.

Generating electricity - the fundamentals

An electrical generator is usually a rotating device that continuously moves an assembly of ***conductors*** through the ***magnetic field***. Obeying ***Faraday's law*** of ***electromagnetic induction***, this movement creates the ***electromotive force*** (EMF) necessary to drive an ***electric current***. The generator is rotated by some form of engine, often a ***turbine***. Of course, this turbine must be driven by some other source of energy. It is these sources of energy that form the topic of much debate and concern.

Burning fossil fuels

Fossil fuels, such coal, oil or natural gas, are ***hydrocarbons*** and are easily burned. These fuels are commonly used as sources of heat in ***thermal power stations*** in which heat energy is converted into electricity. The heat either converts water into steam or ignites fuel (similar to a combustion engine) which then drives a turbine (***mechanical energy***).

When fossil fuels are burned they produce ***carbon dioxide*** (CO_2) and ***nitrous oxide*** (N_2O), These are greenhouse gases that contribute to the modern problem of ***global warming***. In addition, fossil fuels take tens of millions of years to form naturally and are now classified be ***non-renewable***. Accordingly, the focus is now on ***renewable energy*** sources i.e. sources that are replenished naturally over a reasonable period of time. These include water, wind, the sea, the sun, heat from the earth itself and organic matter (***biomass***).

Using the energy of water

When water falls from a height its ***potential energy*** converts to ***kinetic energy***. In a ***hydroelectric*** (or ***hydropower***) station this flow is directed onto the blades of a turbine, causing it to rotate and drive the generator.

The river Liffey offers natural falls that are very suitable sites for hydro stations. There are three stations on the river, at Poulaphouca, Golden Falls and Leixlip.

The first, and most famous, hydro station in Ireland is at Ardnacrusha in Co Clare. A project before its time, in 1929 the output of 86 MW (megawatt) could meet the needs of the whole country. It is still the largest river station in the country.

The 86 MW hydroelectric power station on the Shannon at Ardnacrusha

Harnessing the wind

The power of the wind can also be used to drive a turbine. These turbines are much smaller than those used in hydro stations – a typical example would be around 2 MW. Of course a ***wind farm*** contains a number of turbines, so the combined output is much higher.

In Ireland, the wind is stronger and more regular at high altitudes and on coastal sites. Accordingly, these are the best locations on land for effective wind farms.

The ESB farm at Carnsore Point, Co. Wexford is situated at most south-easterly corner of the country. This site is exposed to wind from both the Celtic Sea (Atlantic) and Irish Sea. The farm has a capacity of about 12 MW, which is enough to supply the current demand of about 7,600 households. The largest ESB farm is located in Derrybrien in south-east Co Galway. It has 70 turbines with a combined capacity of about 60 MW, which is enough for some 38,000 households.

The 12 MW wind farm at Carnsore Point with its 14 turbines

Of course, the wind does not blow all the time and, when it does, its speed varies. The time over which the wind is consistently suitable for a turbine is called ***full load hours***. The average Ireland is about 31% of the time.

Turning the sun's heat into electricity

A ***solar cell*** is an arrangement of ***semiconductor*** material. When ***photons*** in sunlight falls on a semiconductor such as silicon they are absorbed and energy is transferred to electrons in the material. These electrons can then escape from the atoms and be harnessed as an electrical current. This is called the ***photovoltaic effect*** and a solar cell is also known as a ***photovoltaic cell*** (PV).

It is estimated that 25% of buildings in the country will be using solar energy by 2025. Accordingly, the ESB is involved in pioneering work with solar energy organisations in the USA and the UK.

Generating renewable energy

The unit of energy

Energy and Work: **joule** (J). A joule is the energy transferred (work done) to an object when a force of one **newton** accelerates the object through a distance of one metre.

In electrical terms a joule is the energy dissipated as heat when an electric current of one **ampere** passes through a resistance of one **ohm** for one second. An ampere (or amp) is the flow of one coulomb of electrical charge per second.

Power: watt (W). A watt is one joule per second (1 W = 1 J/s)

Note that these are all ***SI units***. Many non-SI units still exist. For example, the term 'horsepower' is often used for engines. Also, the term 'calorie', used on food and drink labels is a not an SI energy unit.

The energy of the sea

Influenced by the rotation of the earth and the gravitational pull of the moon, the sea is a powerful source of kinetic energy. ***Wave power*** systems use the kinetic energy of the surface waves. ***Tidal power*** systems harness the kinetic energy of the moving tide water. These energies can then be transformed to mechanical energy used to drive turbines and generators. Since Ireland is surrounded by seas it is expected that these technologies will play an important part in our future. Indeed, it is estimated that 20% of our electricity could be provided in this way. Experiments have already started off the coast of Co Clare with a project titled ESB Westwave. A school demonstration can be viewed at: *https://youtu.be/8hhwbhsOvGs*.

Burning organic material

Biomass is ***organic matter*** such as plants or plant-based materials which are not used for food or feed. Such non-fossil materials are burned to produce heat or converted to other forms of liquid ***biofuels*** such as ***bioethanol*** and ***biodiesel***. The ESB is currently planning biomass power plants in the UK.

What is geothermal energy?

The Earth holds a vast store of thermal energy known as ***High Temperature Geothermal Energy***. Most of this energy has been present since the planet's formation and more is generated by ***radioactive decay***. The earth's core is extremely hot (around 5,000°C) and is continuously conducted towards the surface. Heat pumps can be used to transfer some of this heat to buildings. Heat pumps can also cool a building in the summer by transferring heat back to the Earth. In the SuperHomes project in Co Tipperary houses are fitted with heat pumps that actually use the heat from the air during the summer. They are also equipped with solar panels. (*www.superhomes.ie*)

Sustainability is essential

The term 'sustainability' relates to the need to ensure that we do not deprive future generations by using up available energy resources or by damaging the environment in an irreversible manner. The obvious way of ensuring sustainability is the use renewable resources. In this lesson we have discussed some of the main technologies involved. It may be surprising to realise that the energy sources mentioned – water, biomass, solar etc. – have always been available to the human race. The missing element has been the technology to transform them effectively. The ESB is at the forefront of the sustainability drive in our country and elsewhere.

Energy for generations

ESB is Ireland's foremost energy company, and the largest supplier of renewable electricity in Ireland. Through innovation, expertise and investment, ESB is leading the way in developing a modern, efficient electricity system, capable of delivering sustainable and competitive energy supplies to customers in the 'all-island market' - the Republic of Ireland, Northern Ireland, England, Wales and Scotland.

Established in 1927, ESB operates right across the electricity market, from generation through transmission and distribution to supply. ESB also operates in a range of complementary sectors including telecommunications, international engineering consultancy and gas.

Today, ESB operates a renewable energy portfolio that has the capacity to supply over 830 MW of green energy to the homes, farms, hospitals, schools and businesses of Ireland and the United Kingdom. Its goal is to reduce ESB's carbon emissions 40% by 2025, and towards becoming carbon-neutral by 2050. ESB aims to achieve this through expanding its wind portfolio, and continually investing in other renewable energy technologies that take advantage of the natural resources available to us.

For further information visit: www.esb.ie

ESB 'all-islands' asset map. (https://www.esb.ie/our-businesses/generation-energy-trading-new/generation-asset-map)

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Syllabus References

The main syllabus references for the lesson are:

Leaving Certificate Physics (pp. 27, 29, 37, 39)
- Energy and Power: Energy as the ability to do work.
- Mass as a form of energy: $E = mc^2$ (nuclear energy)
- Conversions from one form of energy to another. Principle of conservation of energy.
- Heat as a form of energy.
- Electromagnetic induction. Photoelectric effect

Leaving Certificate Technology (p. 22)
- Energy and Energy Conservation. Electricity

Leaving Certificate Biology (p. 33)
- Ecosystem; Energy Flow; Human Impact

Science and Technology in Action is also widely used in **Junior Certificate Science** and in **Transition Year**.

Learning Outcomes

On completion of this lesson, students should be able to:

- Explain what is meant by the term 'energy'
- List different forms of energy and describe common energy conversions
- Outline different ways of generating electricity
- Discuss the advantages and disadvantages of different electrical generation technologies, including environmental considerations
- Identify the energy sources that are likely to meet Ireland's future needs
- Describe some of the projects in which ESB is involved.

General Learning Points

These are additional relevant points which are used to extend knowledge and facilitate discussion.

- At Coolkeeragh in Co. Down ESB operates a 455 MW Combined Cycle Gas Turbine (CCGT). This is over 50% more efficient than traditional gas turbines and emits much lower levels of nitrogen oxide (NO_x) and sulphur dioxide (SO_2) pollutants.
- In 2014, renewable electricity generation, consisting of wind, hydro, landfill gas, biomass and biogas, accounted for 22.7% of gross electricity consumption in Ireland. (Energy in Ireland, *www.seai.ie*)
- Aghada Power Station is one of the most efficient and cleanest plants in Europe. A detailed presentation on how the power station operates is available at: http://ESBGeneration.esb.ie
- Related teaching notes have been forwarded to all schools and can also be ordered by emailing: esbwebmaster@esb.ie

Student Activities

1. What steps can be taken to make more efficient use of energy or reduce energy loss in your home or school? Examples include: solar heating panels, photovoltaic panels, wind power and improved insulation. Summarise your findings in a poster or computer presentation.
2. Most electrical units are named after people who made important discoveries relating to electricity: **coulomb, volt, ampere, watt, joule, ohm**. Devise a poster, or a computer presentation, on one of these units. Your presentation should include
   - relevant images
   - a biography of the person in whose honour the unit is named
   - an explanation of the unit and what it measures
   - how the unit relates to other SI units.
3. The wind turbines at Carnsore are rated at 850 kW (0.85 MW) each. More recent wind farms use 1.5 MW to 3 MW turbines.
   - What is the maximum power output of a wind farm with fifty 1.5 MW turbines?
   - Calculate the average power of the wind farm if the load factor is 30%.
   - Calculate the average energy, in kilowatt hours (kW h), produced by the wind farm in one year.
   - In Ireland the average yearly electrical energy use per household is about 5300 kW h (kilowatt hours). Approximately how many households could be supplied with electricity by the wind farm described above?

True/False Questions

a)	Energy cannot be created but can be destroyed.	**T**	**F**
b)	Heat cannot be used to generate electricity.	**T**	**F**
c)	All types of electricity generation are not equally efficient.	**T**	**F**
d)	There is not enough sunlight in Ireland to use solar energy.	**T**	**F**
e)	Most electricity is generated from renewable sources.	**T**	**F**
f)	The sea could be an important source of energy in the future.	**T**	**F**
g)	ESB does not manage any wind farms.	**T**	**F**
h)	Wind will not be a significant source of energy in the future.	**T**	**F**
i)	In a hydro station, the kinetic energy of moving water is converted to electrical energy.	**T**	**F**
j)	The SI unit of energy is the erg.	T	F
k)	A kilowatt-hour is a unit of power.	T	F
l)	One kilowatt-hour is equal to 3,600,000 joules.	T	F

Check your answers to these questions on www.sta.ie.

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Examination Questions

Junior Certificate Science (HL) 2005, Q. 15 b

- What energy conversion occurs in a generator (dynamo)?
- Draw a labelled diagram of a simple generator (dynamo).
- Electricity is transmitted as a.c. and its voltage is increased leaving the generating station and then is reduced before it reaches your home. Name a device that can change a.c. voltage.

Leaving Certificate Physics (HL) 2005, Q. 11 b

Read the following passage and answer the accompanying questions.

The scientist whose research would unite electricity and magnetism was Michael Faraday. He developed the first electric motor in 1821, showing that a current carrying conductor could be made to revolve around a magnet. He went on to expand on Oersted's observation that an electric current produces a magnetic effect. Perhaps, Faraday thought, the opposite was also true: a moving magnetic field could generate an electric current. This was to be called electromagnetic induction. Soon he had created the first electric generator, and everyday life would never be the same again. His experiments with induced currents produced the transformer. *(Adapted from Milestones of Science; Curt Supple; 2000)*

(i) List three factors that affect the force on a current-carrying conductor placed near a magnet.

(ii) What energy transformation takes place in an electric motor?

(iii) What is the function of a commutator in a d.c. motor?

(iv) Draw a sketch of the output voltage from an a.c. generator.

(v) How are the slip rings connected to an external circuit in an a.c. generator?

(vi) A transformer and an induction coil can both be used to change a small voltage into a larger voltage. What is the basic difference in the operation of these two devices?

(vii) Name the Irish physicist who invented the induction coil.

(viii) Give two factors that affect the efficiency of a transformer.

Leaving Certificate Physics (HL) 2011, Q. 10 b (part)

- What changes can be made to a d.c. motor to convert it to an a.c. generator?
- Draw a sketch of the output voltage from an a.c. generator.
- Give two ways in which the output voltage from an a.c. generator can be increased.

Leaving Certificate Physics (OL) 2001, Q. 3

(i) Define energy.

(ii) What is the unit of energy?

(iii) Write down Einstein's equation which relates mass and energy.

(iv) State the principle of conservation of energy.

(v) An electrical generator converts _____energy to _____ .

Did You Know?

- By 2020, ESB will be generate one third of its electricity from renewable sources and will achieve carbon net-zero by 2035.
- Energy from renewable sources is also known as 'green energy'.
- The power of a wind turbine is proportional to the cube of the wind velocity.
- Biomass is the oldest fuel used by mankind. Wood has been used as a fuel for cooking and heating for over 500,000 years.
- The word 'turbine' derives from the Latin 'turbo' meaning 'vortex'.
- Ardnacrusha was constructed at the same time as the first national electricity grid (110 kV) and became the model for large scale electrification schemes all over the world.
  See the *Nationwide* programme on the History of Ardnacrusha at *www.youtube.com/watch?v=TMClV8Z0HYs*
- The ESB station at Turlough Hill in Wicklow is an example of a pumped storage hydroelectric system. When there is spare capacity, water is pumped from a lower reservoir back to the upper reservoir.

James Prescott Joule (1818 - 1889)

James Prescott Joule was an English physicist who studied the relationship between heat and mechanical work. As a young man, one of his tutors was John Dalton, himself a famous scientist.

Joule's work gave rise to the law of conservation of energy. He shares the credit or this with Hermann Helmholtz, another famous scientist. Joule also made important advances in the development of thermodynamics. He was extremely interested in electricity and discovered the well known relationship between power and current, $P = I^2R$. This relationship is known as Joule's First Law (also known as the Joule-Lenz Law (after Heinrich Lenz)

The SI derived unit of energy, the joule, is named in his honour.

Revise The Terms

Can you recall the meaning of the following terms?
Revising terminology is a powerful aid to recall and retention.

accelerating, ampere, biodiesel, bioethanol, biomass, biofuel, carbon dioxide, conductor, electric current, electricity, electromagnetic induction, electromotive force, energy, Faraday's law, force, fossil fuel, full load hours, global warming, High Temperature Geothermal Energy, hydrocarbon, hydroelectric, hydropower, kinetic energy, law of conservation, magnetic field, mechanical energy, nitrous oxide, non-renewable, ohm, organic matter, photon, photovoltaic cell, photovoltaic effect, potential energy, power, radioactive decay, renewable energy, semiconductor, SI units, solar cell, thermal power station, tidal power, turbine, wave power, work.

Check the Glossary of terms for this lesson on www.sta.ie