Core topics

Essential idea: Societies are completely dependent on energy resources. The quantity of energy is conserved in any conversion but the quality is degraded.

C.1 Energy sources

Nature of science:

Use theories to explain natural phenomena—energy changes in the world around us result from potential and kinetic energy changes at the molecular level.

Energy has both quantity and quality. (2.2)

Understandings:

- A useful energy source releases energy at a reasonable rate and produces minimal pollution.
- The quality of energy is degraded as heat is transferred to the surroundings. Energy and materials go from a concentrated into a dispersed form. The quantity of the energy available for doing work decreases.
- Renewable energy sources are naturally replenished. Non-renewable energy sources are finite.
- $\text{Energy density} = \frac{\text{energy released from fuel}}{\text{volume of fuel consumed}}$.
- $\text{Specific energy} = \frac{\text{energy released from fuel}}{\text{mass of fuel consumed}}$.
- $\text{The effeciency of an energy transfer} = \frac{\text{useful output energy}}{\text{total input energy}} \times 100\%$.

Applications and skills:

- Discussion of the use of different sources of renewable and non-renewable energy.
- Determination of the energy density and specific energy of a fuel from the enthalpies of combustion, densities and the molar mass of fuel.
- Discussion of how the choice of fuel is influenced by its energy density or specific energy.

International-mindedness:

- The International Energy Agency is an autonomous organization based in Paris which works to ensure reliable, affordable and clean energy for its 28 member countries and beyond.
- The International Renewable Energy Agency (IRENA), based in Abu Dhabi, UAE, was founded in 2009 to promote increased adoption and sustainable use of renewable energy sources (bioenergy, geothermal energy, hydropower, ocean, solar and wind energy).

Theory of knowledge:

- "I have no doubt that we will be successful in harnessing the sun's energy. If sunbeams were weapons of war we would have had solar energy centuries ago." (Lord George Porter). In what ways might social, political, cultural and religious factors affect the types of research that are financed and undertaken, or rejected?
- There are many ethical issues raised by energy generation and its consequent contributions to pollution and climate change.What is the influence of political pressure on different areas of knowledge?

Utilization:

Syllabus and cross-curricular links:
Topic 5.1—enthalpies of combustion
Topic 10.2—the combustion of hydrocarbons
Environmental systems and societies topics—3.2, 3.3, 3.5 and 3.6
Physics topic 8.1—energy density

C.1 Energy sources	
• Determination of the efficiency of an energy transfer process from appropriate data. • Discussion of the advantages and disadvantages of the different energy sources in C.2 through to C.8.	**Aims:** • **Aim 1**: Discussions of the possible energy sources provide opportunities for scientific study and creativity within a global context. • **Aim 6**: The energy density of different fuels could be investigated experimentally. • **Aim 7**: Databases of energy statistics on a global and national scale can be explored here. • **Aim 8**: Energy production has global economic and environmental dimensions. The choices made in this area have moral and ethical implications.

Essential idea: The energy of fossil fuels originates from solar energy which has been stored by chemical processes over time. These abundant resources are non-renewable but provide large amounts of energy due to the nature of chemical bonds in hydrocarbons.

C.2 Fossil fuels

Nature of science:

Scientific community and collaboration—the use of fossil fuels has had a key role in the development of science and technology. (4.1)

Understandings:

- Fossil fuels were formed by the reduction of biological compounds that contain carbon, hydrogen, nitrogen, sulfur and oxygen.
- Petroleum is a complex mixture of hydrocarbons that can be split into different component parts called fractions by fractional distillation.
- Crude oil needs to be refined before use. The different fractions are separated by a physical process in fractional distillation.
- The tendency of a fuel to auto-ignite, which leads to "knocking" in a car engine, is related to molecular structure and measured by the octane number.
- The performance of hydrocarbons as fuels is improved by the cracking and catalytic reforming reactions.
- Coal gasification and liquefaction are chemical processes that convert coal to gaseous and liquid hydrocarbons.
- A carbon footprint is the total amount of greenhouse gases produced during human activities. It is generally expressed in equivalent tons of carbon dioxide.

Applications and skills:

- Discussion of the effect of chain length and chain branching on the octane number.
- Discussion of the reforming and cracking reactions of hydrocarbons and explanation how these processes improve the octane number.
- Deduction of equations for cracking and reforming reactions, coal gasification and liquefaction.

International-mindedness:

- The choice of fossil fuel used by different countries depends on availability, and economic, societal, environmental and technological factors.
- Different fuel rating systems (RON, MON or PON) are used in different countries.
- Ocean drilling, oil pipelines and oil spills are issues that demand international cooperation and agreement.

Utilization:

Syllabus and cross-curricular links:
Topics 5.1 and 5.3—enthalpy changes of combustion
Topics 10.1 and 20.3—hydrocarbons and isomerism
Topic 10.2 and option C.5—global warming
Option C.8—solar cells
Biology topic 4.3—carbon cycling

Aims:

- **Aim 6**: Possible experiments include fractional distillation and catalytic cracking reactions.
- **Aim 7**: Databases of energy statistics on a global and national scale can be explored here.
- **Aim 7**: Many online calculators are available to calculate carbon footprints.
- **Aim 8**: Consideration of the advantages and disadvantages of fossil fuels illustrates the economic and environmental implications of using science and technology.

C.2 Fossil fuels	
• Discussion of the advantages and disadvantages of the different fossil fuels. • Identification of the various fractions of petroleum, their relative volatility and their uses. • Calculations of the carbon dioxide added to the atmosphere, when different fuels burn and determination of carbon footprints for different activities. **Guidance:** • The cost of production and availability (reserves) of fossil fuels and their impact on the environment should be considered.	

Essential idea: The fusion of hydrogen nuclei in the sun is the source of much of the energy needed for life on Earth. There are many technological challenges in replicating this process on Earth but it would offer a rich source of energy. Fission involves the splitting of a large unstable nucleus into smaller stable nuclei.

C.3 Nuclear fusion and fission

Nature of science:

Assessing the ethics of scientific research—widespread use of nuclear fission for energy production would lead to a reduction in greenhouse gas emissions. Nuclear fission is the process taking place in the atomic bomb and nuclear fusion that in the hydrogen bomb. (4.5)

Understandings:

Nuclear fusion

- Light nuclei can undergo fusion reactions as this increases the binding energy per nucleon.
- Fusion reactions are a promising energy source as the fuel is inexpensive and abundant, and no radioactive waste is produced.
- Absorption spectra are used to analyse the composition of stars.

Nuclear fission

- Heavy nuclei can undergo fission reactions as this increases the binding energy per nucleon.
- ^{235}U undergoes a fission chain reaction:
  $^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{236}_{92}U \rightarrow$ X + Y + neutrons.
- The critical mass is the mass of fuel needed for the reaction to be self-sustaining.
- ^{239}Pu, used as a fuel in "breeder reactors", is produced from ^{238}U by neutron capture.
- Radioactive waste may contain isotopes with long and short half-lives.
- Half-life is the time it takes for half the number of atoms to decay.

International-mindedness:

- The use of nuclear energy is monitored internationally by the International Atomic Energy Agency.
- High-energy particle physics research involves international collaboration. There are accelerator facilities at CERN, DESY, SLAC, Fermi lab and Brookhaven. Results are disseminated and shared by scientists in many countries.
- The ITER project is a collaboration between many countries and aims to demonstrate that fusion is an energy source of the future.

Theory of knowledge:

- The use of nuclear energy carries risks as well as benefits. Who should ultimately be responsible for assessing these? How do we know what is best for society and the individual?

Utilization:

Syllabus and cross-curricular links:
Topic 2.1—isotopes
Topic 2.2—the emission spectrum of hydrogen
Physics topic 7.2—nuclear fusion

Aims:

- **Aim 7**: Computer animations and simulations of radioactive decay, and nuclear fusion and fission reactions.
- **Aim 8**: Consideration of the environmental impact of nuclear energy illustrating

C.3 Nuclear fusion and fission	
Applications and skills: *Nuclear fusion* • Construction of nuclear equations for fusion reactions. • Explanation of fusion reactions in terms of binding energy per nucleon. • Explanation of the atomic absorption spectra of hydrogen and helium, including the relationships between the lines and electron transitions. *Nuclear fission* • Deduction of nuclear equations for fission reactions. • Explanation of fission reactions in terms of binding energy per nucleon. • Discussion of the storage and disposal of nuclear waste. • Solution of radioactive decay problems involving integral numbers of half-lives. **Guidance:** • Students are not expected to recall specific fission reactions. • The workings of a nuclear power plant are not required. • Safety and risk issues include: health, problems associated with nuclear waste and core meltdown, and the possibility that nuclear fuels may be used in nuclear weapons. • The equations, $N = N_0 e^{-\lambda t}$ and $t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$ are given in section 1 of the data booklet.	the implications of using science and technology.

Essential idea: Visible light can be absorbed by molecules that have a conjugated structure with an extended system of alternating single and multiple bonds. Solar energy can be converted to chemical energy in photosynthesis.

C.4 Solar energy

Nature of science:

Public understanding—harnessing the sun's energy is a current area of research and challenges still remain. However, consumers and energy companies are being encouraged to make use of solar energy as an alternative energy source. (5.2)

Understandings:

- Light can be absorbed by chlorophyll and other pigments with a conjugated electronic structure.
- Photosynthesis converts light energy into chemical energy:
  $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$
- Fermentation of glucose produces ethanol which can be used as a biofuel:
  $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$
- Energy content of vegetable oils is similar to that of diesel fuel but they are not used in internal combustion engines as they are too viscous.
- Transesterification between an ester and an alcohol with a strong acid or base catalyst produces a different ester:

  $RCOOR^1 + R^2OH \rightarrow RCOOR^2 + R^1OH$
- In the transesterification process, involving a reaction with an alcohol in the presence of a strong acid or base, the triglyceride vegetable oils are converted to a mixture mainly comprising of alkyl esters and glycerol, but with some fatty acids.
- Transesterification with ethanol or methanol produces oils with lower viscosity that can be used in diesel engines.

Applications and skills:

- Identification of features of the molecules that allow them to absorb visible light.

Theory of knowledge:

- The claims of "cold fusion" were dismissed as the results are not reproducible. Is it always possible to obtain replicable results in the natural sciences? Are reproducible results possible in other areas of knowledge?

Utilization:

Syllabus and cross-curricular links:
Topic 5.3—bond enthalpies
Topic 20.1—mechanism of nuclear substitution reactions
Biology topic 2.9—photosynthesis

Aims:

- **Aim 2**: The conversion of solar energy is important in a number of different technologies.
- **Aim 6**: Experiments could include those involving photosynthesis, fermentation and transesterification.
- **Aim 8**: Transesterification reactions, with waste cooking oil, could reduce waste and produce excellent biofuels.

C.4 Solar energy	
• Explanation of the reduced viscosity of esters produced with methanol and ethanol. • Evaluation of the advantages and disadvantages of the use of biofuels. • Deduction of equations for transesterification reactions. **Guidance:** • Only a conjugated system with alternating double bonds needs to be covered.	

Essential idea: Gases in the atmosphere that are produced by human activities are changing the climate as they are upsetting the balance between radiation entering and leaving the atmosphere.

C.5 Environmental impact—global warming

Nature of science:

Transdisciplinary—the study of global warming encompasses a broad range of concepts and ideas and is transdisciplinary. (4.1)

Collaboration and significance of science explanations to the public—reports of the Intergovernmental Panel on Climate Change (IPCC). (5.2)

Correlation and cause and understanding of science—CO_2 levels and Earth average temperature show clear correlation but wide variations in the surface temperature of the Earth have occurred frequently in the past. (2.8)

Understandings:

- Greenhouse gases allow the passage of incoming solar short wavelength radiation but absorb the longer wavelength radiation from the Earth. Some of the absorbed radiation is re-radiated back to Earth.
- There is a heterogeneous equilibrium between concentration of atmospheric carbon dioxide and aqueous carbon dioxide in the oceans.
- Greenhouse gases absorb IR radiation as there is a change in dipole moment as the bonds in the molecule stretch and bend.
- Particulates such as smoke and dust cause global dimming as they reflect sunlight, as do clouds.

Applications and skills:

- Explanation of the molecular mechanisms by which greenhouse gases absorb infrared radiation.
- Discussion of the evidence for the relationship between the increased concentration of gases and global warming.
- Discussion of the sources, relative abundance and effects of different greenhouse gases.
- Discussion of the different approaches to the control of carbon dioxide emissions.

International-mindedness:

- This issue involves the international community working together to research and reduce the effects of global warming. Such attempts include the Intergovernmental Panel on Climate Change (IPCC) and the Kyoto Protocol which was extended in Qatar.

Theory of knowledge:

- Some people question the reality of climate change, and question the motives of scientists who have “exaggerated” the problem. How do we assess the evidence collected and the models used to predict the impact of human activities?

Utilization:

Syllabus and cross-curricular links:
Topics 7.1 and 17.1—equilibrium systems
Topic 8.2—acid–base equilibria
Topic 11.3—infrared spectra
Topic 13.2—transition metal complexes
Biology topic 4.4—climate change
Physics topic 8.1—thermal energy transfer

Aims:

- **Aim 6**: The equilibrium between aqueous and gaseous carbon dioxide could be experimentally investigated.

C.5 Environmental impact—global warming	
• Discussion of pH changes in the ocean due to increased concentration of carbon dioxide in the atmosphere. **Guidance:** • Greenhouse gases to be considered are CH_4, H_2O and CO_2.	• **Aim 7**: Computer modelling is a powerful tool by which knowledge can be gained about the greenhouse effect. • **Aim 8**: Discussions of climate change and green chemistry raise awareness of the ethical, economic and environmental implications of using science and technology.