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Energy for the Future, Superheroes Need Not Apply

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Introduction

Is the idea of inexpensive and environmentally safe energy only a dream? The blockbuster movie *TheAvengers* conveys a story about the evil Loki stealing the infinitely powerful "Tesseract" from S.H.I.E.L.D., an international peace keeping agency. The superheroes, Captain America, Iron Man, The Hulk and Thor must come to save the world from destruction because the power of the "Tesseract" is in evil hands. In the 2009 blockbuster, *Avatar*, having depleted our own resources on Earth, we had to travel 4.3 light years to the moon Pandora to mine "Unobtainium" to supply our need for energy. [1] Are these just stories or do they speak to the global need for clean, safe energy? My curriculum unit will address the issues surrounding global energy supply. The curriculum unit will explore the physical laws associated with the production of energy alternatives, energy degradation, and energy density. Students will research energy alternatives and the global energy supplies and develop a plan to provide a country with safe, clean energy for the next twenty-five years. Will this be a job only superheroes can do? Will we have to travel to a fictional moon? The answer is no, but we will have to make difficult decisions based on scientific laws and facts.

Classroom and School Environment

I teach at an urban, partial magnet high school with a total population of roughly 1800 students, with approximately 750 students who are part of the International Baccalaureate (IB) magnet. The school is comprised of approximately 52 % Africans American, 25 % white, 16% Hispanics and 6 % Asian. More than 50% of the student population is on free and reduced lunch. I will be using the curriculum unit in my IB physics III class; the students in this course are on their third class in physics, having completed an honors-level physics class as sophomores and as seniors they have completed science course in biology, earth and environmental science and normally chemistry. The IB physics course is a college level physics curriculum divided over two years that includes a minimum of 40 hours of experimental work.

Rational

The aims of the International Baccalaureate Physics course is to expose students to the most fundamental experimental science, which seeks to explain the universe from the smallest particles to an understanding of the origins of the universe. Yet more importantly, students will study the impact of physics on society, the moral and ethical dilemmas, and the social economic and environmental impact of the work of scientists in a global context. A unit of study in the IB physics core curriculum is on energy, power and climate change. The most important objective for students to gain from this curriculum unit is an understanding that scientifically based decisions made by world leaders based on the best available information will impact our lives and environment in the future. I want students to understand the physics behind these decisions and have a sense of the difficulty in making informed choices based on science but also on risk analysis and management to meet the energy requirement of the future.

My curriculum unit will include a review of energy and the laws that manage the transfer and cyclical nature of energy. Students will research and compare alternative energy sources based on energy density, costs, advantages and disadvantages. The final project in the curriculum unit will require students to form a global energy panel and outlining energy policy for an assigned region of the world to meet the energy needs and environmental concerns for the next 25 years.

Objectives

The IB objectives addressed in my curriculum unit include revisiting energy topics addressed in the first year of IB Physics, such as forms of energy and the laws of thermodynamic as they relate to creation of work in a cyclical process. Students will learn about and discuss energy degradation. They will construct and analysis energy flow diagrams and identify where the energy is degraded. Students will research and understand the different world energy sources comparing energy density, direct and indirect costs, environmental impact and advantages and disadvantages of each source of energy.

The common core objectives addressed in my curriculum unit are from standard five, matter and energy, where students understand the properties of energy in its various forms and the processes by which energy is exchanged and transformed. In addition, common core standard seven identifies and evaluates the uses of the Earth's resources. My curriculum unit will integrate all of these standards into a project where students will research and synthesize their knowledge about energy resources.

The Details of Energy

Energy is a crucial factor of our survival. We as humans cannot do anything without energy. If you are not convinced of this fact, try to not eat for a week and you will know what it is like to have no energy. Energy is defined as the ability to do work. So what is work? Work is using a force to move a mass though a distance. It is very much like lifting a book to a table or walking around the block. The great news about energy is that energy is conserved. It is a law of nature, specifically, the first law of thermodynamics. It states that energy is neither created nor destroyed but changed from one form to another. Here, however, is the bad news. The second law of thermodynamics, which states that energy always goes from a more useful form to a less useful form, means that energy is constantly changing forms to something that cannot be used to do work.

Energy is grouped into three categories: kinetic energy, potential energy, and rest energy. Kinetic energy is energy due to a mass moving. Anything that moves has kinetic energy from the car speeding on a highway to the molecules moving in your hot coffee, in addition to electrons moving a current in a circuit. Kinetic energy is also in sound waves and electromagnetic waves of light. All this kinetic energy is doing work, moving a mass through a distance. Work is done in moving a car and in moving an electron in a circuit.

Potential energy is stored energy in a field. For example, a compressed spring or water behind a dam can be used to do work later. Potential energy is stored in the chemical bonds of fossil fuels and in electric fields of capacitors.

Rest energy is the energy stored in the nucleus of the atom. When two or more protons form the nucleus of an atom, some of the proton's mass is converted to energy. This energy is called the binding energy and is found using Einstein's famous $E=mc^2$ formula. The Sun's energy is derived from the binding of hydrogen in nuclear fusion to form helium and, as a result, energy is released during this reaction. The energy released from the sun is in the form of electromagnetic waves or light, which the earth receives. We use the binding energy in nuclear reactors to create heat and electrical energy in nuclear power plants.

The Laws of Thermodynamics

The conservation of energy is the most widely applicable law of nature. It is the governing principle from supernova to the operations of the cells in your body. When I first introduce the concept of energy, I discuss the first law of thermodynamics, it states that energy is neither created nor destroyed but changed from one form to another, and use a roller coaster as an example. We use a motor to move a car to the top of the first hill and then release the car. The gravitational potential energy stored in the car propels the car to the bottom of the hill at great speed and then back to the top of the next hill slowing down as the kinetic energy is converted back to gravitational potential energy. If there is no friction between the wheels of the car and the track, the car will return to the same height on the second hill. However, if there is friction, some of the energy is converted to heat. The track will get hotter and the wheels of the car will also increase in temperature. Energy is conserved but some of the energy is converted to heat and eventually the roller coaster car will come to a stop.

The second law of thermodynamics restricts the conversion of heat energy to useful work and there are multiple ways to state the second law. One way to state this is heat energy always flows from hot (high energy) to cold (lower energy). Again, the concept of the second law of thermodynamics is very simplistic but the implications are much more complicated. For example, to make something colder than its surroundings, work must be done on the system (energy input). The next part of the second law states that it is impossible to build an engine or cycle that only converts heat into an equivalent amount of work. This means that NOTHING is 100% efficient. In all heat cycles, some energy is dissipated to the environment as waste heat.

The result of the second law is high energy heat sources deposit heat to lower temperature reservoirs, then heat from these lower temperature reservoirs deposit heat to still lower temperature reservoirs until the accumulated waste heat ends up in the environment. For example, if coal is burned as a source of electrical energy, only about one-third of the energy in the coal can be transmitted to our homes as electrical energy; the other two-thirds goes to the atmosphere as waste heat. [2] Modern electrical generators that convert mechanical energy into electrical energy are within a few percent of the maximum efficiency dictated by the second law of thermodynamics. Ultimately, the second law of thermodynamic tells us we cannot get something from nothing.

Sources of Energy and Energy density

At the end of the last century more than ninety percent of all energy used by humans originated from fossil fuels. [3] Why do we love Fossil fuel? Fossil fuels pollute the atmosphere with carbon dioxide and other pollutant that cause acid rain. We have to dig them from deep within the earth, which destroys the landscape and creates other forms of pollution. It is because of fossil fuel's potential energy. Fossil fuel comes from the sunlight falling on the earth millions of years ago being converted and stored in chemical energy of the cell of plants and animals. So how does fossil fuel compare to other energy alternatives. To make a comparison we need to have a common unit for all energy sources, and that common unit is energy density of the energy per kilogram. If we look at the energy in one pound of fat, it has about 3600 Calories of energy or about 15 million Joules of energy per pound. That is why it takes so much work to burn off an extra pound of fat. If we convert the pound to kilogram there is about 33 million joules of energy per kilogram of fat. Gasoline has about 46 million joules of energy per kilogram a factor of 1.4 times greater. Below is a chart of energy density of common sources of energy in mega (million) joules per kilogram. The values listed are approximate due to variation in the chemical composition. [4]

Table 1.1 Energy Density in MJ/kg

energy form	MJ/kg
Clock spring	0.0000003
Capacitor	0.000002
Water at 100 m dam	0.001
AA battery	0.59
Lithium (best) battery	2.54
TNT	4.61
Nitroglycerine	6.36
Wood	16
Mass of earth in orbit	33
Fat	33
Coal	24
Gasoline	46
Hydrogen	142
Pure Uranium fission	80,000,000
H-3 H-3 fusion	330,000,000
Antimatter	180,000,000,000

The most striking values on this table are the energy stored in the nucleus of atoms and antimatter. It is clear why when the idea of nuclear fission became an option as a source of energy it was stated "too cheap to meter." [5] Nuclear fusion and antimatter are not possible sources of energy today but could be future sources. The only chemical energy source available with greater energy per kilogram than gasoline is hydrogen. There are two problems with using hydrogen as a fuel source. First, there is not a source of pure hydrogen we must separate it from water or other hydrogen containing compounds, and which takes energy to separate. Secondly, hydrogen is a gas at room temperature and one kilogram of hydrogen will have four times the volume of one kilogram of gasoline so, hydrogen has 4.5 times less energy than a gallon gasoline and 30-40% of the energy available is used in producing the pure hydrogen. [6] We love gasoline because is has a lot of energy per kilogram.

Notice solar, wind and hydro energy are not listed on the table. That is because they are not chemically stored sources of energy. They are power sources. Power is the rate at which energy is produced or used, measured in kilowatts or kilojoules per second. The average American home uses about one kilowatt (or 1000 joules per second) of power. [7] The sun provides approximately one kilowatt of energy per square meter when it is directly overhead. That is enough to power the average America home and is equivalent to one gigawatt per square kilometer enough power for a million homes. Except, solar cells at best are only about 15% efficient in converting the electro-magnetic energy of the sun into the electrical energy we desire. The area to produce one gigawatt of power is about 50 square miles. [8] In addition, power from solar energy would still have to be stored in batteries for use during cloudy days or at night, which is an additional cost and efficiency issue.

Wind energy is a valid alternative energy source in selected regions around the world. A wind farm of 130 wind turbine generators has been proposed on the ocean off the coast of Massachusetts to supply commercial power. The projected area used is 28 square miles and it will produce a maximum of 0.43 gigawatts of power and a yearly average of 1.5 gigawatt-hours. [9] Other alternative such as geothermal, wave and tidal sources are possible in selected regions, but the ability to produce significant amount of power in the near future is limited.

In Table 1.2 the approximate energy cost for various power sources are listed in kilowatt-hours. Notice the cost for fossil fuels are all greater then the cleaner alternatives such as nuclear, hydro and wind. What is prominent on this table is the cost of batteries, which needs to be addressed to students because, generally, they have no clue as the true cost to buy batteries even, rechargeable cell phone batteries.

Table 1.2 Energy Cost in $ per KWH

Source	Direct Cost	Indirect Cost	Total
Coal	0.03	0.07	0.10
Natural gas	0.05	0.03	0.08
Gasoline	0.11		0.11
Computer battery	4.00		4.00
AAA battery	1000.00		1000.00
Solar panel	0.18		0.18
Nuclear fission	0.02	0.01	0.03
Hydro	0.03		0.03
Wind	0.03		0.03

Table Notes: Direct cost includes capital cost, operation, maintenance and fuel costs. Indirect costs include social and environmental costs. Indirect costs not listed have not been qualified. [10]

Energy Alternatives

The first student assignment will be to develop a class presentation of energy sources and alternatives. Each student or group of students will be assigned a source of energy from the following: fossil fuels, nuclear, solar, wind, hydro, which includes wave and tidal. The students will prepare a class presentation on how their particular source produces power, cost per kilowatt-hour, efficiency in the form of a sankey diagram. A sankey diagram is a graphic that illustrates the flow of material or energy where the width of the arrow is proportional to the magnitude. In addition to a description of the power provided by the source of energy, environmental concerns and a direct comparison of advantages and disadvantages must be presented and discussed. The students will make 15-minute presentation to the class on the energy alternatives and a scoring rubric for the student's presentation is in Appendix 3.

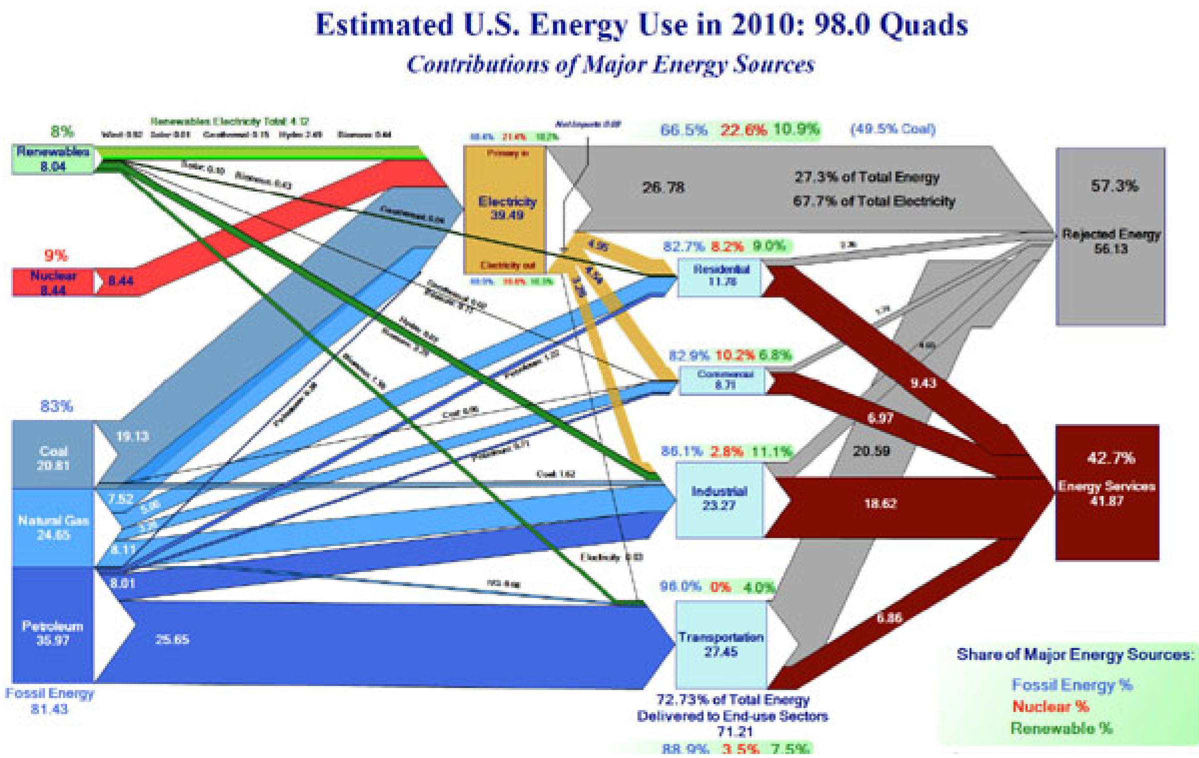
World Energy and Energy for the Future

Described above are the science and facts about energy, the energy density and the costs of the different energy resources. My students will make presentations on the different energy sources available today, but what will we use in the future and how will it impact our climate and economy worldwide is the real question. We love fossil fuels because they have lots of stored energy and are efficient to use. We will exhaust the supply of oil reserves, but coal will last for centuries. Coal is environmentally the worst source of energy. [11] Is nuclear energy a valid alternative or is solar and wind the best alternative? How will our energy needs and sources develop in the future? I want my students to research world energy uses and supplies and develop an energy policy that meets energy needs for one region of the world for the next 25 years.

Strategies for future Energy

One of the activities required will be to have my students to watch the TED debate on nuclear energy sources verse green energy, solar and wind power. [12] TED (Technology Entertainment and Design) is a global set of conferences curated by the American private non-profit Sapling Foundation, TED talks are devoted to "ideas worth spreading." [13] In this debate both sides make a powerful case for each energy alternative my students will gain insight into the difficulty in making energy choices and the advantages and disadvantage.

First, lets look at how the United States meets its energy needs today. Below is the sankey diagram for the United States energy supply for 2010; it was prepared by Eric Shuster [14] . It represents the various sources of energy on the left. The energy uses in the middle and the percentage of useful energy on the right. In 2010, the US used 98 quads or quadrillion BTUs of energy, which is 103,475,260,000 gigajoules of energy. That is equivalent to 331 gigajoules per person per year or 12kW per person. [15] I am going to ask my students to calculate how many times they would have to climb to the top of the Empire State building to perform and equivalent amount of work to their average daily energy use. The answer is approximately 3900 times to the 86th floor observation level.



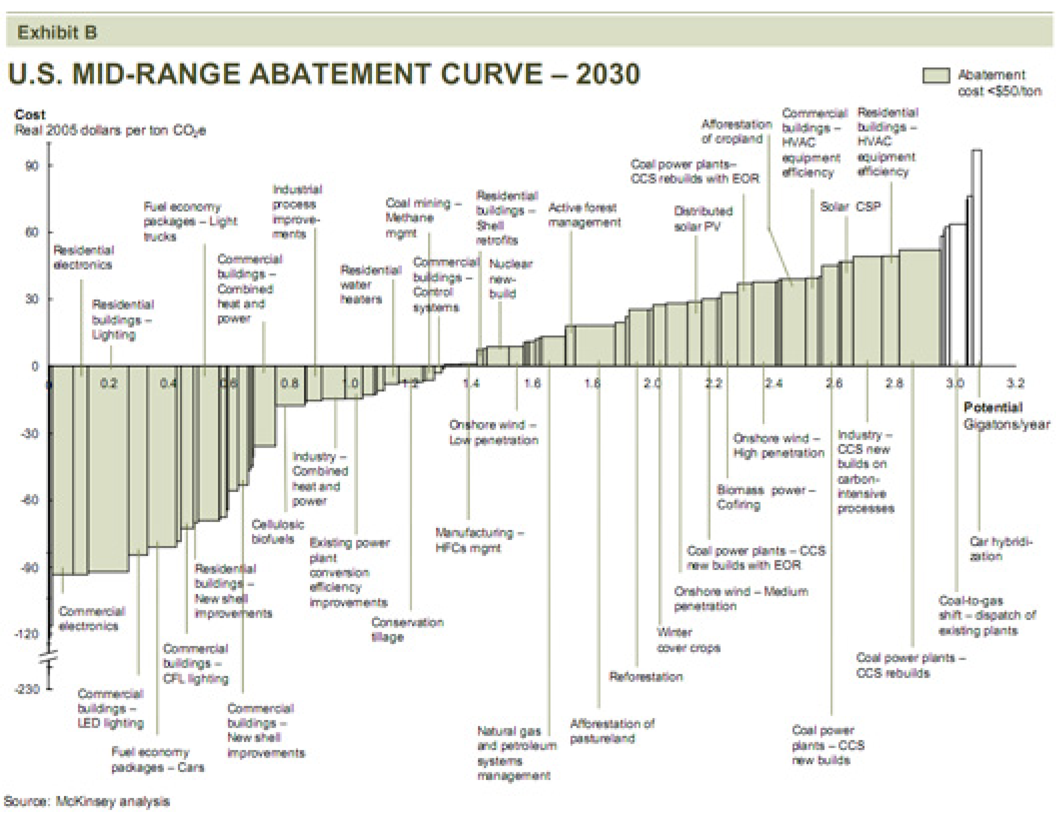
A study and class discussion of this one diagram could cover several class periods but I will have to limit it to stay within the scope of other parts of my curriculum. The first point to discuss is the amount of rejected energy compared to useful energy. The discussion will be scaffold by questioning such as how can we decrease rejected energy into useful energy? How can we reduce the dependence on oil by changing the fuel used in automobiles? My students need to understand that a change in fuel used in automobiles will not fix all future energy problems such as carbon dioxide emission because transportation of all kinds only account for 28% of our energy use, industry account for 23%, commercial and residential combined 20% and 30% of the energy is rejected as waste heat. In addition, the predict US energy sankey diagram for 2025 is in Appendix 3 along with world oil consumption and carbon dioxide production diagrams [16] .

Global Energy Commission

The capstone project for my curriculum unit will be the creation of the Global Energy Commission (GEC). The commission consists of energy leaders from the eight industrial countries currently in the G8, the informal group of advanced industrialized economies, and six emerging market economies namely China, India, Brazil, South Africa and Mexico. Each student will be assigned as the leader of one country; they will be responsible for developing a twenty-five year energy blueprint for their country. The Global Energy Commission will then have their annual conference and each nation will have to present and defend their energy policy to the commission leadership. Their energy plan must address and try and answer the following questions: Where will energy in your region come from? How will it be used? What will it cost? And what are the environmental impacts of your choice? How will you manage the risks of your choices? Now, I know if any high-school student could answer these questions then there would not be an energy problem but the outcome of this panel is to explore the option of energy supply and demand. How these choices effect the economic and environmental implication. Each country in the world has different choices to from the source to the disposal. This is perfect forum to discuss personal choice in limiting energy use because energy conservation is one method to meet the future energy demands.

To frame my students thoughts on how to develop an energy policy to meet their energy needs for the next 25 year I will have my students review the most recent International Energy Agency, IEA, world energy outlook reports and fact sheet. [17] The World Energy Council has "Survey of Energy Resources" which lists the energy resources available in each country in the world. [18] The two major ideas they must meet is Energy Security and Environmental impact. Energy security is the country must be energy independent or self sufficient, if their source of energy is imported then their source of energy is not secure and can affect economics and world safety. Students must use the natural resource of their region, no solar power in the northern latitudes and no biomass if your country has little land mass. Students must address energy security. Students must also address environmental impact from the use of fossil fuels and nuclear waste. I want students to come to one conclusion that conservation in all forms meets both security and environmental issues.

To help student meet environmental issues students will be given the McKinsey analysis of the cost per ton of carbon dioxide produced for 2030. [19] The diagram shows the research in the cost of reducing carbon emission. It has two parts, the downward bars are actions that are profitable they make money while reducing carbon emission and energy use. The upward bars present ways to reduce carbon dioxide that will cost money. This includes generation methods that are more expensive than coal but do not emit carbon, such as nuclear, solar, and wind. It also includes carbon capture and sequestration (CCS). [20]



Students will have to strike a balance between environmental impact in the form of global warming and energy security and present their ideas to solve the energy crisis to me and the other students that form the Global Energy Council. I can not wait to see their presentations and how creative they can be in solving the problem of economical, safe, clean energy.

Appendix 1 Annotated Bibliography

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"2010 Survey of Energy Resources." *2010 World Energy Council* 22, no. 1 (2010): 618. Can be found at world energy.org ISBN:9780946121021 This is a review of status of the world's major energy resources not only fossil fuels but other major types

Appendix 2 IB Objectives

Topic 8: Energy, power and climate change—Assess. Statements 2008.09

8.1 Energy degradation and power generation

Statement Number	Assessment Statement	Obj
8.1.1	State that thermal energy may be completely converted to work in a single process, but that continuous conversion of this energy into work requires a cyclical process and the transfer of some energy from the system.	1
8.1.2	Explain what is meant by degraded energy	3
8.1.3	Construct and analyze energy flow diagrams (Sankey diagrams) and identify where the energy is degraded.	3
8.1.4	Outline the principal mechanisms involved in the production of electrical power	2

8.2 World energy sources

Statement Number	Assessment Statement	Obj
8.2.1	Identify different world energy sources	2
8.2.2	Outline and distinguish between renewable and non-renewable energy sources	2
8.2.3	Define the *energy density* of a fuel	1
8.2.4	Discuss how choice of fuel is influenced by its energy density	3
8.2.5	State the relative proportions of world use of the different energy sources that are available.	1
8.2.6	Discuss the relative advantages and disadvantages of various energy sources	3

8.3 Fossil fuel production

Statement Number	Assessment Statement	Obj
8.3.1	Outline the historical and geographical reasons for the widespread use of fossil fuels	2
8.3.2	Discuss the energy density of fossil fuels with respect to the demands of power stations	3
8.3.3	Discuss the relative advantages and disadvantages associate with the transportation and storage of fossil fuels	3
8.3.4	State the overall efficiency of power stations fuelled by different fossil fuels	1
8.3.5	Describe the environmental problems associated with the recovery of fossil fuels and their use in power stations	2

8.4 Non-fossil fuel power production

Nuclear power

Statement Number	Assessment Statement	Obj
8.4.1	Describe how neutrons produced in a fission reaction may be used to initiate further fission reactions (chain reaction)	2
8.4.2	Distinguish between controlled nuclear fission (power production) and uncontrolled nuclear fission (nuclear weapons).	2
8.4.3	Describe what is meant by fuel enrichment	2
8.4.4	Describe the main energy transformations that take place in a nuclear power station	2
8.4.5	Discuss the role of the moderator and the control rods in the production of controlled fission in a thermal fission reactor	3
Statement Number	Assessment Statement	Obj
8.4.6	Discuss the role of th heat exchanger in a fission reactor	3
8.4.7	Describe how neutron capture by a nucleus of uranium-238 (^{238}U) results in the production of a nucleus of plutonium-239 (^{239}Pu).	2
8.4.8	Describe the importance of plutonium-239 (^{239}Pu) as a nuclear fuel.	2
8.4.9	Discuss safety issues and risks associated with the productionof nuclear power	3
8.4.10	Outline the problems associated with producing nuclear power using nuclear fusion	2
8.4.11	Solve problems on the production of nuclear power	3

Solar Power

Statement Number	Assessment Statement	Obj
8.4.12	Distinguish between a photovoltaic cell and a solar heating panel	2
8.4.13	Outline reasons for seasonal and regional variations in the solar power incident per unit area of the Earth's surface	2
8.4.14	Solve problems involving specific applications of photovoltaic cells and solar heating panels	3

Hydroelectric power

Statement Number	Assessment Statement	Obj
8.4.15	Distinguish between different hydroelectric schemes	2
8.4.16	Describe the main energy transformations that take place in hydroelectric schemes	2
8.4.17	Solve problems involving hydroelectric schemes	3

Wind power

Statement Number	Assessment Statement	Obj
8.4.18	Outline the basic features of a wind generator	2
8.4.19	Determine the power that may be delivered by a wind generator, assuming that the wind kinetic energy is completely converted into mechanical kinetic energy, and explain why this is impossible	3
8.4.20	Solve problems involving wind power	3

Wave power

Statement Number	Assessment Statement	Obj
8.4.21	Describe the principle of operation of an oscillating water column (OWC) ocean wave energy converter.	2
8.4.22	Determine the power per unit length of a wavefront assuming a rectangular profile for the wave.	3
8.4.23	Solve problems involving wave power	3

8.5 Greenhouse effect

Solar radiation

Statement Number	Assessment Statement	Obj
8.5.1	Calculate the intensity of the Sun's radiation incident on a planet	2
8.5.2	Define *albedo*	1
8.5.3	State factors that determine a planet's albedo	1

The greenhouse effect

Statement Number	Assessment Statement	Obj
8.5.4	Describe the greenhouse effect	2
8.5.5	Identify the main greenhouse gases and their sources	2
8.5.6	Explain the molecular mechanisms by which greenhouse gases absorb infrared radiation	3
8.5.7	Analyze absorption graphs to compare the relative effects of different greenhouse gases	3
8.5.8	Outline the nature of black-body radiation	2
8.5.9	Draw and annotate a graph of the emission spectra of black bodies at different temperatures	2
8.5.10	State the Stefan-Boltzmann law and apply it to compare emission rates from different surfaces	2
8.5.11	Apply the concept of emissivity to compare the emission rates from the different surfaces	2
8.5.12	Define *surface heat capacity*, C_s	1
8.5.13	Solve problems on the greenhouse effect and the heating of planets using a simple energy balance climate model	3

8.6 Global Warming

Statement Number	Assessment Statement	Obj
8.6.1	Describe some possible models of global warming	2
8.6.2	State what is meant by the enhanced greenhouse effect	1
8.6.3	Identify the increased combustion of fossil fuels as the likely major cause of the enhanced greenhouse effect	2
8.6.4	Describe the evidence that links global warming to increased levels of greenhouse gases	2
8.6.5	Outline some of the mechanisms that may increase the rate of global warming	2
8.6.6	Define *coefficient of volume expansion*	1
8.6.7	State that one possible effect of the enhanced greenhouse effect is a rise in mean sea-level	1
8.6.8	Outline possible reasons for a predicted rise in mean sea-level	2
8.6.9	Identify climate change as an outcome of the enhanced greenhouse effect	2
8.6.10	Solve problems related to the enhanced greenhouse effect	3
8.6.11	Identify some possible solutions to reduce the enhanced greenhouse effect	2
8.6.12	Discuss international efforts to reduce the enhanced greenhouse effect	3

Appendix 3 Student Handouts and Diagrams

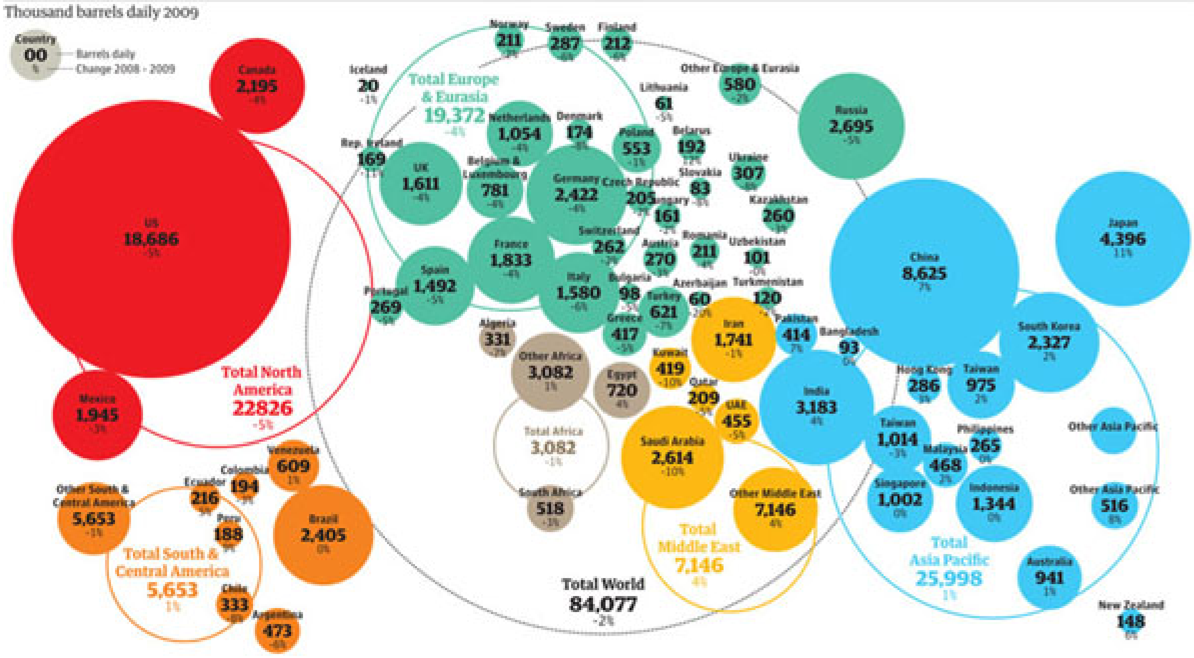
Scoring Rubric for Alternative Energy presentation

Energy Source_________________ Name____________________

Objective	No evidence (0)	Partial (1)	Completely (2)	total
State the energy density of the energy source				
State the relative proportion of world use				
Discuss the advantages and disadvantage of the energy source				
Discuss how power is produced by the energy source				
Discuss the overall efficiency of power production				
Include a Sankey diagram of the power production				

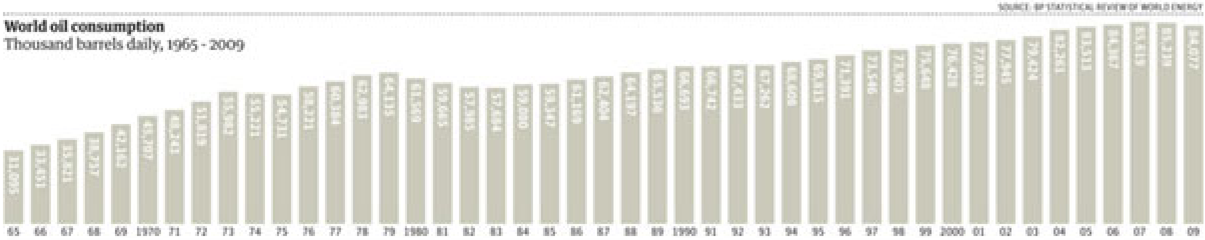
Oil consumption around the world

Thousand barrels daily 2009

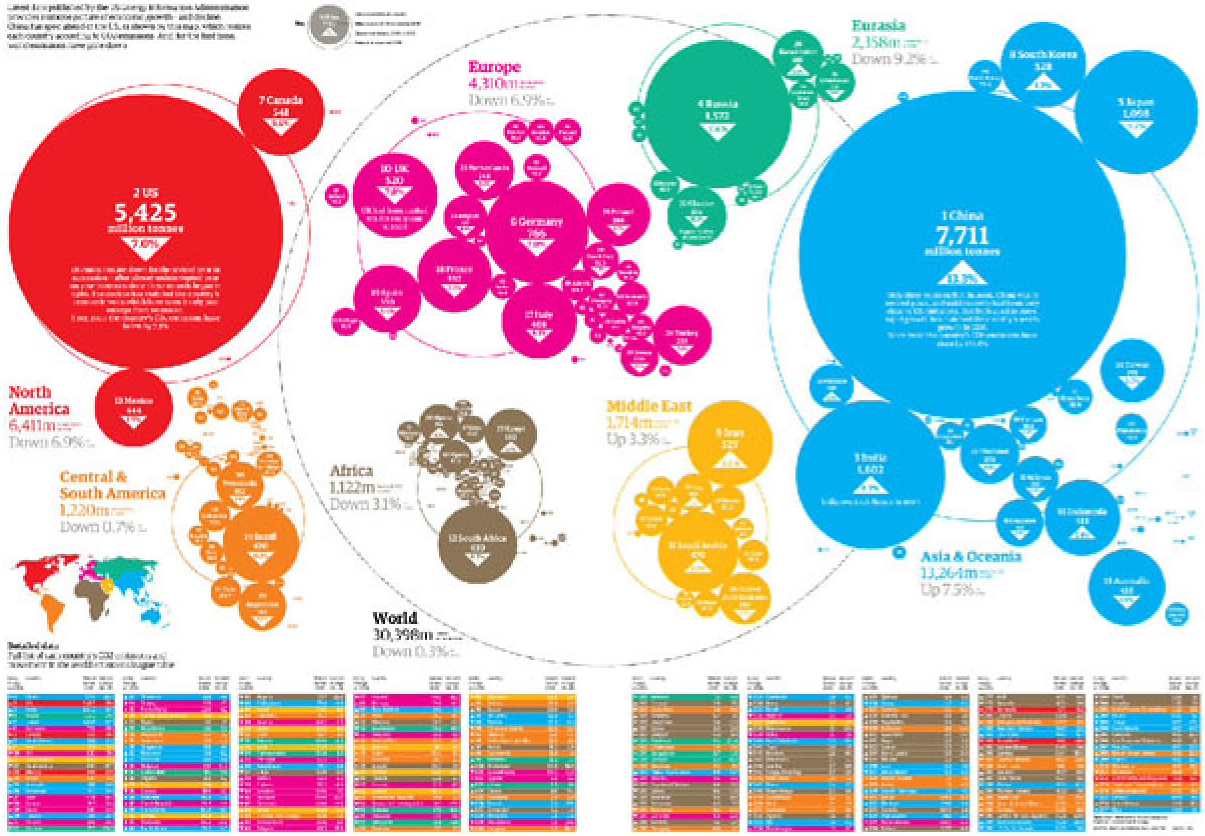


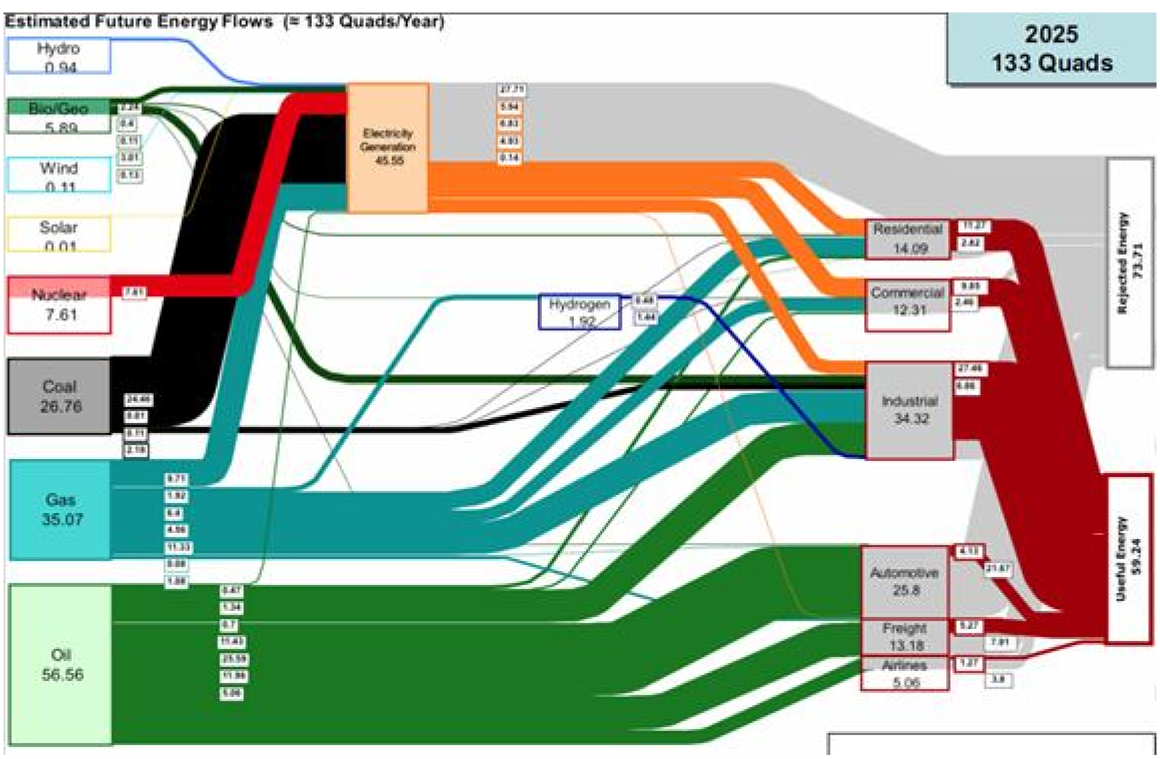
World oil consumption

Thousand barrels daily, 1965 - 2009



An atlas of pollution: the world in carbon dioxide emissions





Endnotes

1. "Movies Avatar and Advengers." Internet Movies Database. ttp://www.imdb.com (accessed July 16, 2012).
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