STEAM EDUCATION GRAND PRIX XPR

Science Education Manual

THE ENVIRONMENT AND CLIMATE CHANGE

Horizon Educational

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HORIZON ENERGY CURRICULUM

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The Environment and Climate Change

1.1 Introduction

Energy is a vital part of modern society– it lights our cities after dark, speeds the movement of people and goods, and powers the continuous advancement of technology. Energy sources such as crude oil and natural gas have been helping humans for more than a hundred years. However, the use of these fossil fuels for power has resulted in many negative consequences; some of these include severe pollution, extensive mining of the world's resources, and strong political influence of countries that have extensive natural resources. In addition, there are concerns that these energy sources will not be able to keep up with the rapid growth of global population.

The world's supply of **fossil fuels** is limited, and these supplies are not evenly distributed throughout the world. This uneven availability of resources has led to regional conflicts and wars. As a growing population causes the demand on this limited supply to increase, the cost of fossil fuels will also likely increase, leading many to predict that the end of low-cost fossil fuels may be approaching. Of course we need fossil fuels to sustain our current living conditions; we can't just stop driving cars, using plastics, or generating electricity. However, the side-effects of these fuels can cause great suffering for people, plants and animals. Carbon dioxide exhaust from these fuels heats the earth's atmosphere and waste from their manufacture and use pollute the Earth's air, water and ground.

This **pollution** makes living conditions worse for all species of the earth. There are both economic and environmental reasons for developing **alternative energy technologies**.

Alternative energy sources first came into the international spotlight in the 1970's when crude oil was suddenly in short supply. Even though there eventually proved to be plenty of fossils fuels left, the crisis awakened the world to the fact that supplies of fossil fuels are limited and eventually will run out. During the past decade, there has been an increased interest in environmentally-friendly and more efficient power production. This interest has rapidly expanded research in alternative fuels and power sources. This renewed interest in alternative energy has come about because of the increasing amount of evidence showing that pollution from fossil fuels is changing the atmosphere of the world. This trend is called global warming, and will continue to worsen due to increased demand for combustion of fossil fuels by a growing world population. The world needs power sources that have low emissions, high energy-efficiency, and an unlimited supply of fuel for a rising world population.

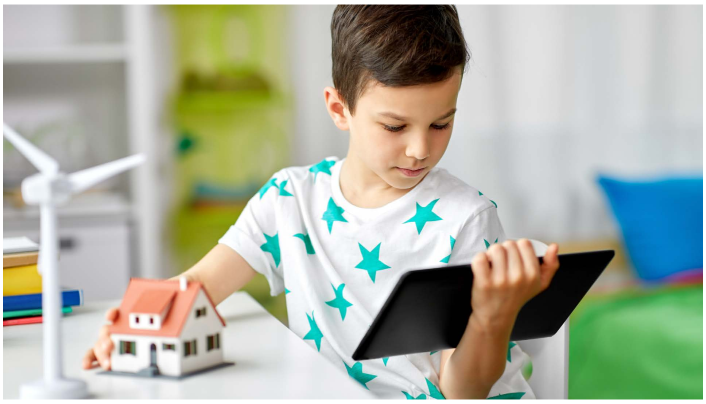


Figure 1-1

Many alternative energy technologies have already been researched and developed. These include solar, wind, hydroelectric power, bioenergy, geothermal energy, and more. Solar cells use the sun to generate electricity, wind power is obtained from the kinetic energy of the wind, and bioenergy is extracted from plants. There are also renewable energies that extract gas from biological waste and harness energy from ocean waves. Each of these alternative energy sources has its advantages and disadvantages and all are in varying stages of development. *Figure 1-2* shows examples of wind, solar and hydroelectric power.

Figure 1-2 - Hydroelectric, wind and solar power

It is advantageous for our Earth and all of the species that inhabit it to be conscious of the energy that we are using. The **Renewable Energy Kit** explores many basic renewable energy technologies: wind, solar, electrolyzer, PEM fuel cell, and a hydrogen storage system. These types of energy can be naturally replenished by our environment. By learning about this technology through experimentation, you can find out exactly how these technologies work. We hope that by conducting experiments with tools such as the Renewable Energy Kit that you will not only learn about the energy technologies explained in the kit but will be inspired to explore alternative energy technologies outside the classroom. This can be as simple as keeping up with the news about climate change or speaking about renewable energy with your friends and family. And maybe exploring these energy technologies today will motivate you to one day improve these technologies or even discover new ones as an engineer or scientist.

1.2 World Energy Demand

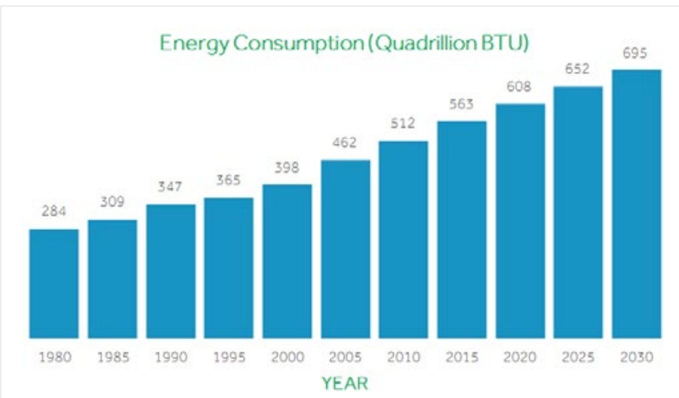


Figure 1-3. World energy consumption, 1980–2030

The use of fossil fuels increased rapidly during the twentieth century and continues to grow: it has quadrupled since the 1970s. The global population consumes petroleum products at a rate 100,000 times greater than the rate that they are formed. China is currently the third largest consumer of oil in the world. However, if a Chinese citizen consumed oil at the same rate as an American citizen, China alone would need 90 million barrels of oil per day to sustain its needs. According to the Energy Information Administration, the typical amount of oil produced in one day by the whole world is only 80 million barrels. Obviously there is something wrong with this equation!

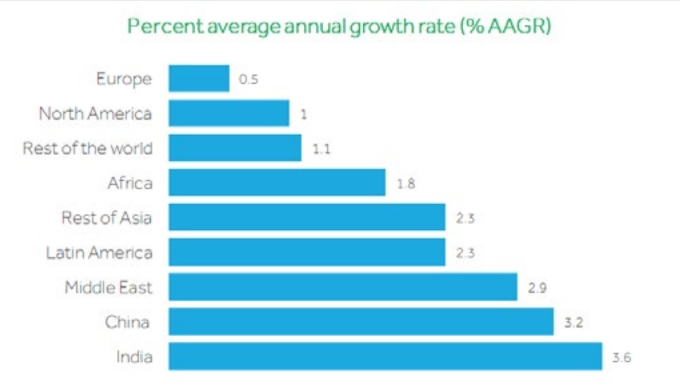


Figure 1-4. Primary energy demand by region (% AAGR is for 1980–2030)

Figure 1-3 shows the current and projected energy consumption from 1980–2030. International energy consumption is estimated to increase by just 2% per year from 2003 to 2030. It doesn't sound like much, but that means total worldwide energy use would grow from 421 quadrillion British thermal units (BTU) in 2003 to 563 quadrillion BTU in 2015 and 722 quadrillion BTU in 2030. World energy demand by region is shown in *Figure 1-4*. As you can see, China and India have energy demands that are growing at a much faster rate than the rest of the world. They're only two countries, but together they make up more than 36% of the world's population, so it's likely that their energy demands will continue to grow for a long time.

The British thermal unit

A unit of energy used in power, steam generation and heating and air conditioning industries. The BTU has largely been replaced by the SI unit of energy, the joule (J), although it is still used in countries such as the United Kingdom, New Zealand, Canada and the United States.

In every country, there are groups that support fossil-fuel taxes in order to reduce the consumption of fossil fuels. There are also groups that are advocates of alternative energy technologies. Many experts are encouraging the reduction of fossil fuel use for industrialized countries, and are promoting the building of their infrastructure to adopt sustainable, renewable sources of power. Approximately 32% of the global population use oil as their primary means of obtaining energy. Coal follows with 27%, Natural Gas has 22% as illustrated in Figure 1-5.

During the 18th and 19th century, coal was the primary fuel used during the **Industrial Revolution**. After automobiles and household electricity became popular, oil became the primary fuel of the 20th century. However, during the last few years, coal has become the fastest growing fossil fuel due to the increased consumption of fossil fuels in China.

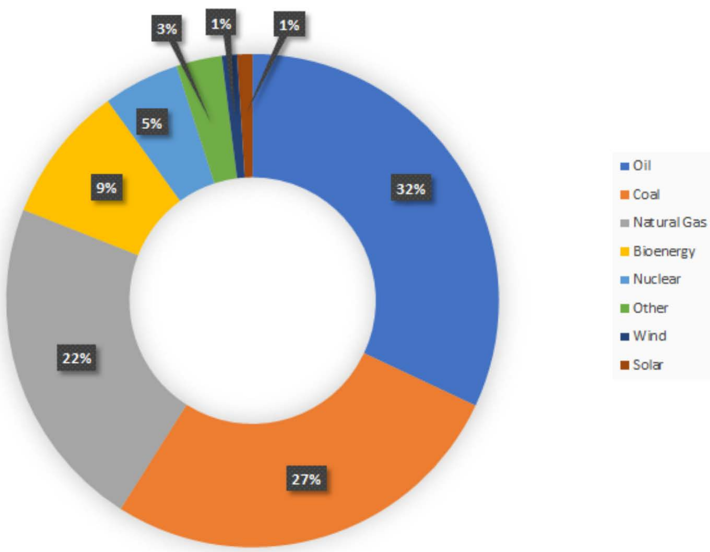


Figure 1-5. World's electricity generation by fuel

Average annual growth rate (% AAGR)

The average increase in growth over the period of one year. It is calculated by taking the arithmetic mean of the growth rate per year. For example, if the energy demand for a region is predicted to be 10% one year, and 20% the next, the AAGR for the two year period would be 15%.

If we're going to have enough energy for the 22nd century, we need to find renewable sources of energy here in the 21st. Although the renewable forms of energy currently have a small percentage of the total energy consumption, they have the highest average annual growth rate (AAGR) compared with all other energy forms as shown in *Figure 1-6*.

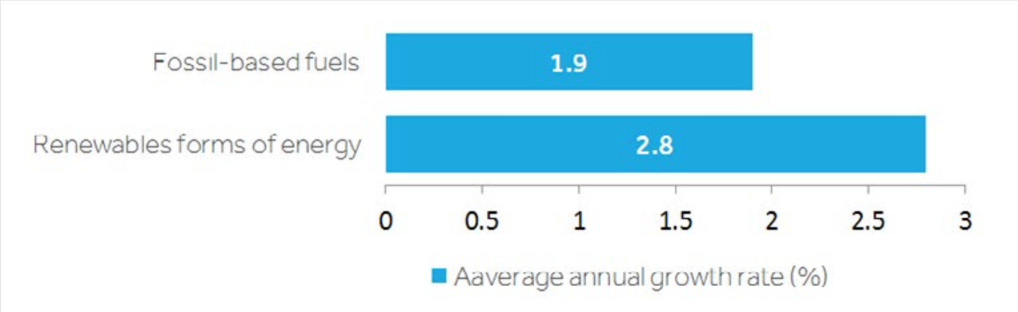


Figure 1-6. Average annual growth rate for renewable and fossil-fuel based energies.png

1.3 Global Warming

Almost everyone has heard of the term "**global warming**", and knows that it means a warming of the planet. However, most of us do not know exactly what this means or how it is measured.

Global warming is the significant increase in the Earth's temperature over a short period of time due to the result of human activities.

Over the course of a century, an increase in temperature of 0.4° Celsius is significant, and an increase of 1° Celsius is considered global warming.

Changes in climate typically take tens of thousands of years. Although 1° or 2° Celsius may not seem like a lot, small temperature changes can have significant effects. After all, the difference between ice at 0° and water at 1° is only 1°, and ice in many parts of the world that has been frozen for thousands of years is now beginning to melt. Small differences in global temperature can even be the difference between our world today and an ice age. When you hear the term "**ice age**," you probably think of the whole world being covered in snow and ice, but the ice during ice ages in Earth's history has only ever covered a small part of the Earth's surface. During the last ice age, when northern North America and northern Europe were covered by glaciers up to 2 miles thick, so much of Earth's water was frozen that the world's sea level fell by more than 100 meters. But, the average global temperature was only 5°C cooler than it is today .

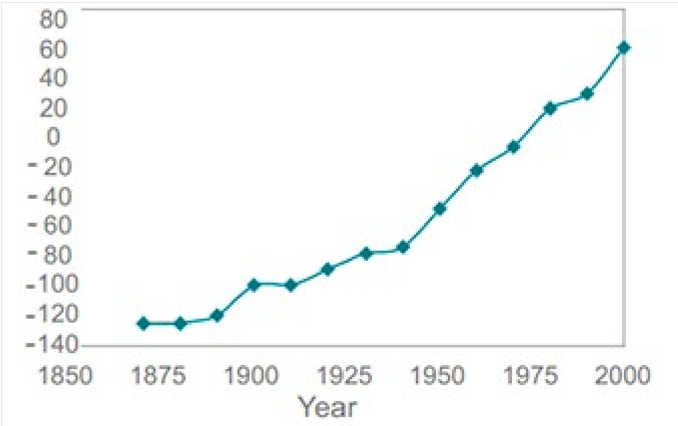


Figure 1.9 – Difference from 1961-1990
– Global average sea level (mm)

Figure 1-9. Difference from 1961-1990
– Global Mean Temperature (°C)

The Intergovernmental Panel on Climate Change (IPCC) is a group of over 2,500 scientists from countries across the world. They met in 2007 to advance climate research. *Figure 1-8* shows their findings on changes in global temperature and sea level. One of the conclusions of this meeting was that the last 15 years have been the warmest since 1850.

Other facts that were found during this conference include :

- **Glaciers** and snow have decreased in the northern and southern hemispheres. Average arctic temperatures have increased by twice the global average during the last 100 years.
- Rain has increased in the Americas, northern Europe and parts of Asia. South Africa and the Mediterranean have been experiencing drying trends.
- Hot days have become more frequent, and cold days have become less frequent and severe.

Natural changes in climate such as heating due to volcanic activity, radiation from the sun, and changes in the chemistry of the atmosphere usually take thousands of

Melting Glacier

years to change only 1°C, but human activity is causing that much change in a much shorter amount of time .

1.3.1 The Greenhouse Effect

Global warming is caused by an increase in the greenhouse effect. The greenhouse effect is generally a good phenomenon because it keeps the earth warm, which enables life to survive. When the sun's energy comes into the earth's atmosphere, about 70% of the energy gets absorbed by the atmosphere, oceans, and land surface while the remaining 30% is reflected into space by the clouds, atmosphere, and surface of the Earth.

The heat that stays on the planet eventually gets radiated out by the atmosphere, oceans, and land masses. Some of the heat gets absorbed into gases (such as carbon dioxide, methane gas and water vapor) in the atmosphere and this trapped heat is what keeps the planet warm. *Figure 1-10* shows the cycle of solar energy and the greenhouse effect. If the earth did not have a greenhouse effect, it would probably look a lot like Mars. Some scientists have suggested that Mars used to have an atmosphere much like Earth's, but that it disappeared long ago. The atmosphere on Mars is now so thin that its air pressure is only 0.6% of Earth's and its average surface temperature is just -55°C. An image of Mars' current atmosphere is shown in *Figure 1-11*.

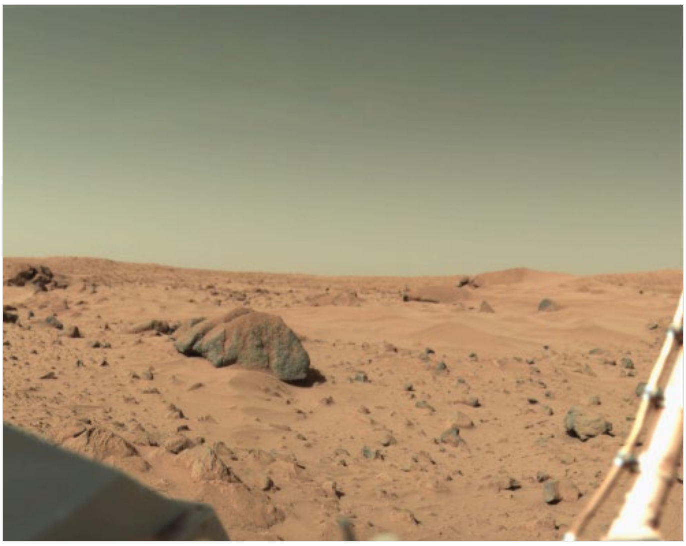


Figure 1-10. This is a Viking image of the surface of Mars.

Another planet in our Solar System shows us what too much greenhouse effect can do. Venus has a thick atmosphere that's 90 times more massive than Earth's and made up of mostly carbon dioxide. The surface temperature on Venus is 465°C, so hot that zinc, lead, and tin would all melt. Even though the planet Mercury is closer to the Sun, it only gets up to 427°C, quite cool compared to the hellish conditions on Venus.

The gases that cause the greenhouse effect have always been a part of Earth's atmosphere. But since the Industrial Revolution, those gases have gone into

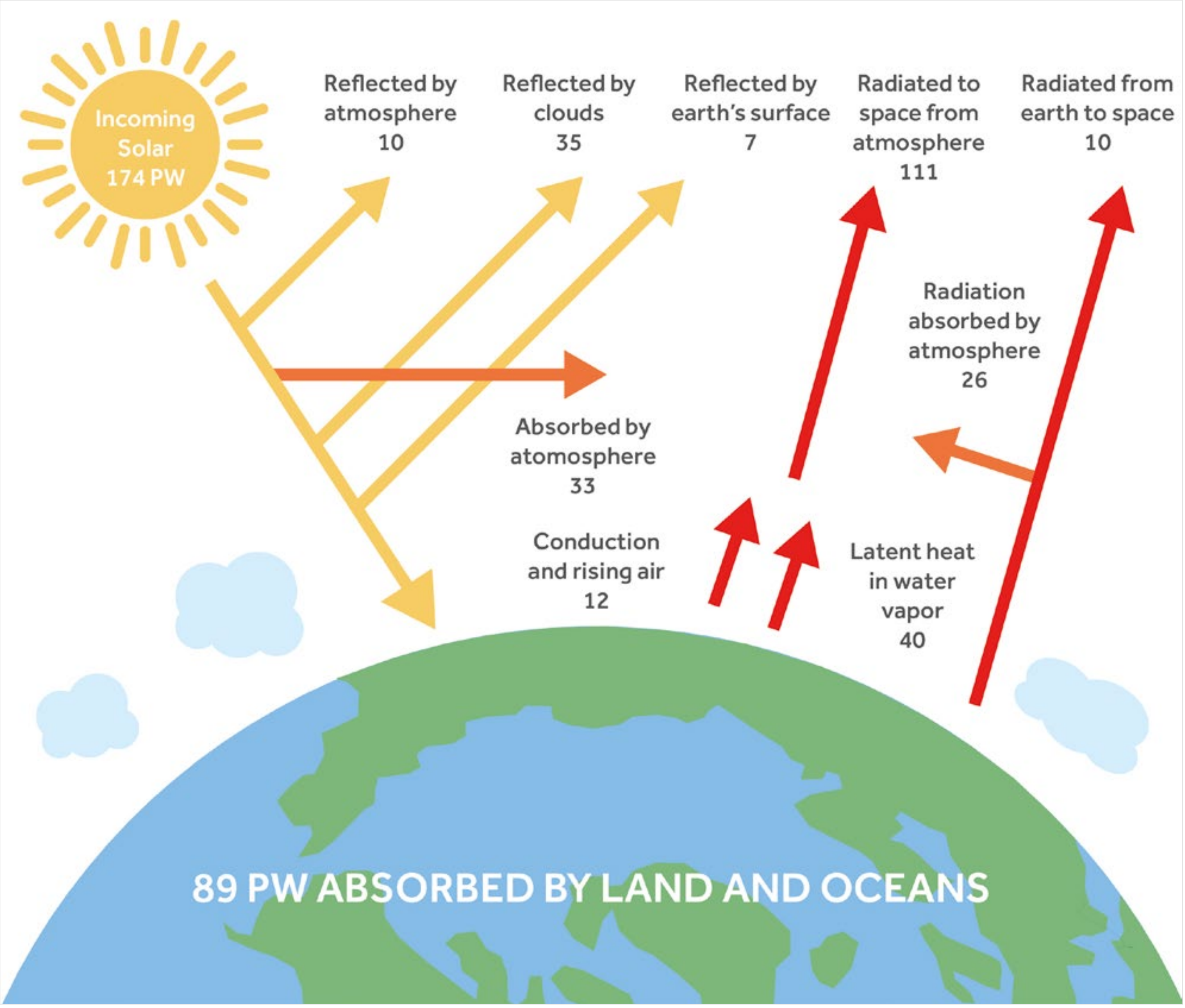
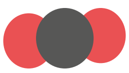


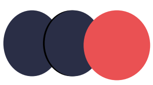
Figure 1-10. Solar energy and the greenhouse effect

the atmosphere at a much higher rate than they would naturally be produced. Some of these gases include [5]:

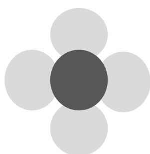


Carbon dioxide (CO_2): This is a colorless gas that is one of the byproducts of the combustion of fossil fuels. Most of the CO_2 currently in the atmosphere was put there from volcanic eruptions millions of years ago. We have been helping to increase carbon dioxide concentration for many years. Carbon dioxide is the primary contributor to global warming because it absorbs infrared radiation. Global CO_2 emissions have increased from 1 billion tons in 1900 to 8 billion tons in 2000.

Nitrous oxide (NO_2): The nitrous oxide levels that

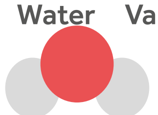


have been released are less than the CO_2 levels, but the amount of energy that NO_2 absorbs is about 270 times as much [5]. NO_2 is another byproduct of the combustion of fossil fuels.



Methane (CH_4): Methane is the main component of natural gas. It is created from the burning of coal, the decomposition of garbage, and from large herds of livestock. It absorbs about 20 times more energy than CO_2, and therefore also heats up the earth.

Water Vapor: The greenhouse effect is also



exacerbated by water vapor but it is usually a result of climate change rather than man-made emissions. When the earth heats up, water vapor forms and rises, and the temperature of the lower air decreases. Eventually, the water vapor cools enough that it converts back into liquid water, and it falls again. As water vapor rises, more of it will condense into the clouds which will help to reflect incoming solar radiation, allowing less energy to enter the earth's atmosphere. *Figure 1-12* illustrates the water cycle of evaporation, condensation, and precipitation. Scientists are uncertain of the exact effect of the increased amounts of water vapor on the earth, but they believe that the concentration of water vapor is correlated with increased amounts of carbon dioxide.

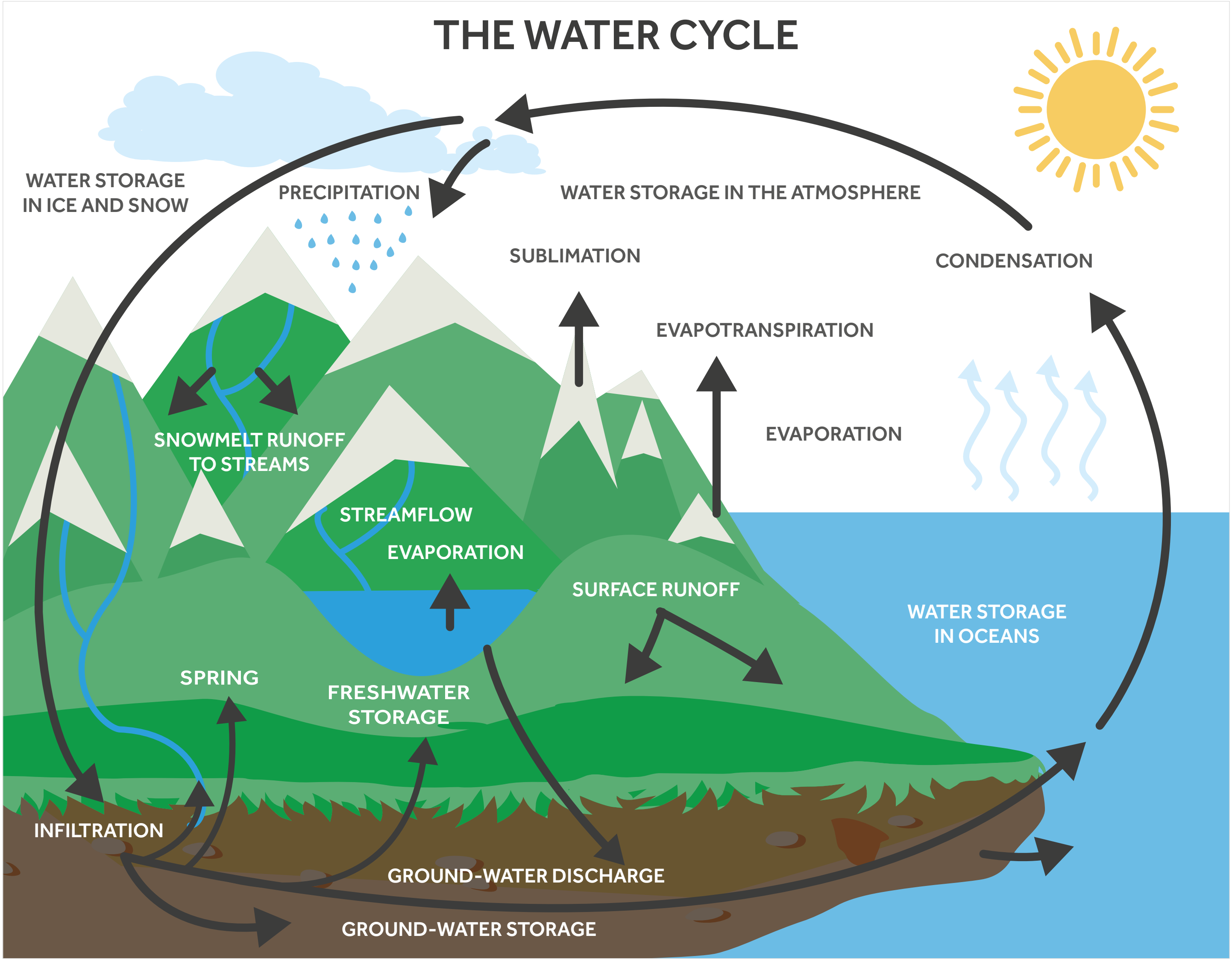


Figure 1-12. Water cycle

1.3.2 Sea Levels

Every summer, as local temperatures increase, ice melts as part of the natural cycle of freeze and thaw illustrated in *Figure 1-13*. But due to the increase in global temperature over recent years, glaciers and sea ice are melting much more than they can accumulate thanks to precipitation in the winter. The loss of large ice masses accelerates global warming since white ice and snow is very good at reflecting sunlight while darker colored water and land is not. Additionally, the melting of large amounts of land-based ice will cause global sea levels to rise. The initial rise would only be an inch or two, but even that small amount can cause flooding for some low-lying coastal areas. If the West Antarctic Ice Sheet, the largest ice sheet on Earth, melted and collapsed into the sea, the sea levels would rise about 10 meters (~32 feet). Cities like New York and London and even whole countries like Micronesia or the Maldives would be underwater.

The continent of **Antarctica** holds about 90% of the world's ice. At its thickest, the Antarctic ice is 2,133 meters (7,000 feet) thick. If all of this ice melted, the oceans would rise approximately 61 meters (200 ft), enough to flood the Bahamas completely and leave all but the tallest hills in Florida underwater. Luckily for those who still want to vacation in Miami, even the recent increase in global temperature has left the average temperature in Antarctica at -37°C, so it won't be melting very soon.

North Pole

At the **North Pole**, the ice is not as thick as in Antarctica and it floats on top of the seawater. If this ice melted, the sea levels would not be affected, the same way melting ice in a glass doesn't affect the level of your drink. However, Greenland also has a large ice covering, and since that ice is on land it would add about 7 meters (20 feet) to the sea level if it melted, enough to put parts of Miami, New York, Los Angeles, Washington, and other cities underwater. Since parts of Greenland are much farther south than the North Pole, it regularly gets above freezing there. Of all the world's major ice sheets, Greenland is likeliest to melt first.

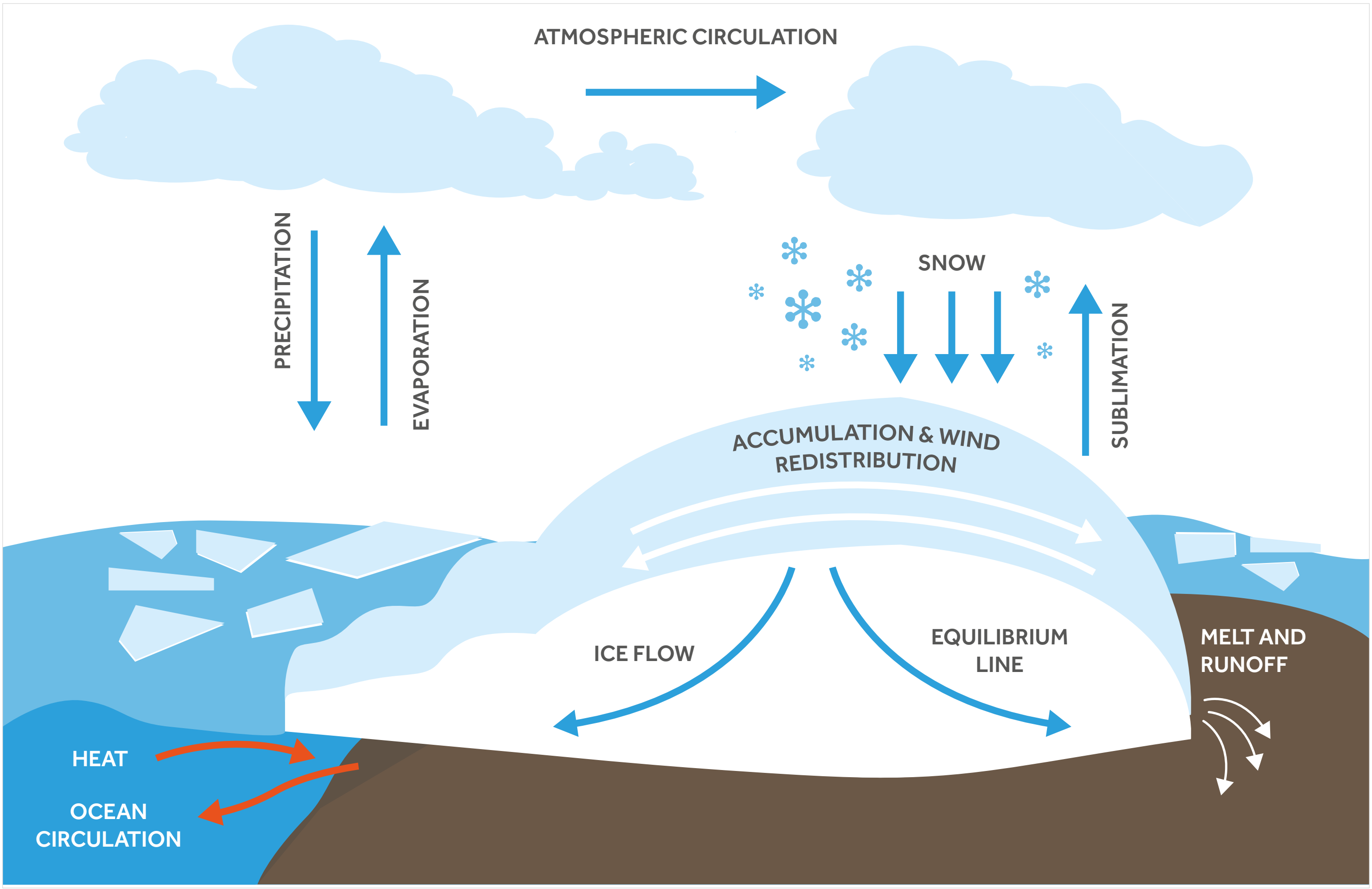


Figure-1-13.-Water-cycle between ocean,atmosphere,and glaciers.

1.3.3 Ecosystem Effects of Global Warming

It is hard to predict the effect of global warming on the ecosystem. Ecosystems are very delicate, and small changes can drastically alter them. Earth's ecosystems are also interconnected; changes to one ecosystem will always affect other ecosystems. An increase in temperature or rain in different areas affects crop growth. It's estimated that approximately $5 billion in crops are lost each year due to ecosystem changes brought on by global warming. For every degree of increase in temperature, there is a 3–5% decrease in crop yields.

Ecosystem

An area that consists of all of the living (plants, animals and micro-organisms) and non-living physical factors of the environment functioning in harmony with one another.

1.3.4 Can We Stop Global Warming?

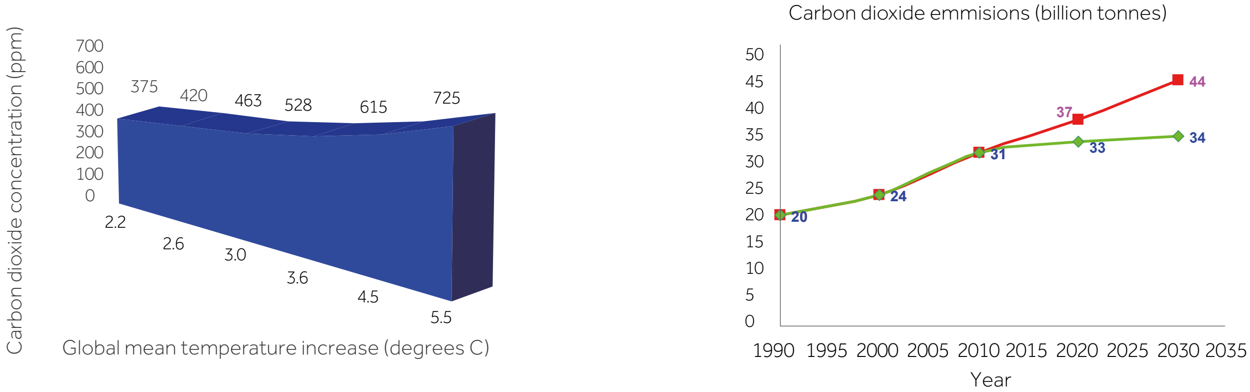
In addition to raising the global temperature, greenhouse gas emissions contribute directly to health problems, acid rain, and the formation of ozone. In many parts of China and India, air pollution remains a public health issue. Acid rain occurs when sulfur dioxide (SO2), sulfur trioxide (SO3) and nitrogen dioxide (NO2) in the atmosphere undergo chemical reactions to form acidic compounds. These are absorbed by water droplets in the clouds, and then fall to the ground, increasing the acidity of the ecosystem. This can damage plant life, soil, and buildings. Most acidic compounds are deposited near the source of contamination, but they can also be carried in the atmosphere for hundreds or thousands of miles. This means pollution created in the U.S. can be carried to China and vice versa.

The current concentration of carbon dioxide in the atmosphere is 180 to 300 ppm. How does this compare to other times in Earth's history? Thanks to bubbles of air trapped in ice, we can get an idea of what the atmosphere was like in the past. Studies of these bubbles have found that our current concentration is far greater than the natural range found over the last 650,000 years. If the CO2 concentration rises to 400–440 ppm, the eventual rise in temperature would be between 2.4 and 2.8 °C.

In order to stabilize the CO2 level, it needs to peak, and then decline. The more quickly that this occurs, the lower the peak stabilization level. According to the IPCC, in order to stabilize the CO2-equivalent concentrations around 445 to 490 ppm, CO2 emissions would need to peak by 2015 (at the latest), and then fall to between 50–85% below the year 2000 levels by 2050. And no, they haven't slowed down enough to peak any time soon. So a later peak will lead to even larger increases

Parts per million (ppm)

A measurement that describes very dilute concentrations of substances. Similar to 1 cent out of one hundred cents (United States cents), parts per milion, ppm, literally means the number of parts out of a milllion. One ppm is equal to one milligram per liter of water (mg/L), or 1 milligram per kilogram soil (mg/kg).



1-14. Carbon Dioxide Concentration and Emission

in temperature. *Figure 1-13* shows the global mean temperature increase with CO2 concentration each year.

Global warming will continue for centuries with the greenhouse gases that have already been released into the atmosphere. Although it seems like a lot of damage has already been done, we can still reduce our impact by doing several things:

Improve energy efficiency: Energy efficiency is the ratio of the energy input to the energy output of a machine. All types of equipment can be made more energy efficient, from cars, to appliances, to the electric grid itself. Any increase in efficiency results in less use of fossil fuels, which in turn reduces greenhouse gas emissions.

Conserve energy: Conserving energy is using less of a service that requires energy, therefore, it lowers emissions. There are countless ways to conserve energy: turning the lights off, using a fan instead of air conditioning, and using less hot water.

Using less carbon intensive fossil fuels: If coal is processed without using Clean Coal Technologies, it emits 75% more carbon per unit of energy than natural gas, and a third more than oil [5]. Therefore, using natural gas instead of coal reduces the emissions' per unit of energy consumed.

Using zero-carbon energy sources: Renewable energy sources such as wind, solar and nuclear power do not produce any CO2. If hydrogen is obtained in a sustainable manner (like in the Renewable Energy Education set), fuel cells also do not produce CO2. These power sources can be used to heat water, swimming pools or entire households and businesses.

Capturing and storing CO2 emissions: There are many technologies that exist to capture and store the CO2 emitted when fossil fuels are burned. These technologies can be used either before or after combustion or both. Some of the places that can store CO2 include depleted oil and gas fields, salt cavities, and unmineable coal beds. The best method of substantially reducing our pollutant emissions is to develop non-fossil fuel sources. Alternative energy sources such as solar, wind and fuel cell power could create large reductions in greenhouse gases if they were widely used.

1.4 Disadvantages of Current Energy Technologies

Current energy technologies include fossil fuels such as coal, oil, gas, as well as nuclear power and chemical energy such as batteries. Coal, oil and gas could likely be in short supply in the near future, as the world population grows rapidly and the world's energy needs increase. We use so much energy that we have to measure it in Zettajoules (ZJ) or 1025 joules.

Joule

A joule (J) is a unit of energy in the International System of Units (SI). It can be defined as the work done to produce one watt of power for one second, so running a 100 watt lightbulb for one second uses 100 joules of energy.

How much energy can we get from the remaining fossil fuels? The estimates vary widely. Figure *1-15* shows an approximate breakdown of the estimated 57 ZJ of oil remaining on the planet. In 2005, the world used 0.18 ZJ of oil. Even if that rate remained constant, proven reserves of oil would run out in a little over 40 years, and any increase in usage as population grows would only shorten that time. But all of these numbers are estimates, and there's much uncertainty about how accurate they really are. The 11 ZJ of future additions to the recoverable reserves could be optimistic.

We have already discussed the disadvantages of fossil fuels several times, but to reiterate, some of the disadvantages of fossil fuels include:

Non-renewable: Fossil fuels are non-renewable resources that take millions of years to form. Therefore, once the reserves are depleted, there is no way to obtain more.

Fossil Fuels – Coal

Pollution: Carbon dioxide is emitted by fossils fuels, which are the main contributor to the greenhouse effect. Coal gives off carbon dioxide, sulphur dioxide and sulphur trioxide, which create acid rain. The acid rain can lead to the destruction of forests, and the erosion of rock and masonry structures. Crude oil has toxic chemicals that cause air pollution when combusted.

Destruction of land: The mining of coal results in the destruction of land.

Dangerous: The mining of coal is considered one of the most dangerous jobs in the world.

Plant location: In order to burn enough fossil fuels to provide energy for the grid, trainloads of fuel are needed on a regular basis. Therefore, this means that the plants should be near fossil fuel reserves.

Oil spills: Oil spills occur, and cause pollution and environmental hazards. They result in catastrophic effects on marine life for many years.

Politics: Many of the countries that have oil reserves are politically unstable. Nations that do not have reserves and have an oil dependence may seek to influence politics of those countries for their own advantage.

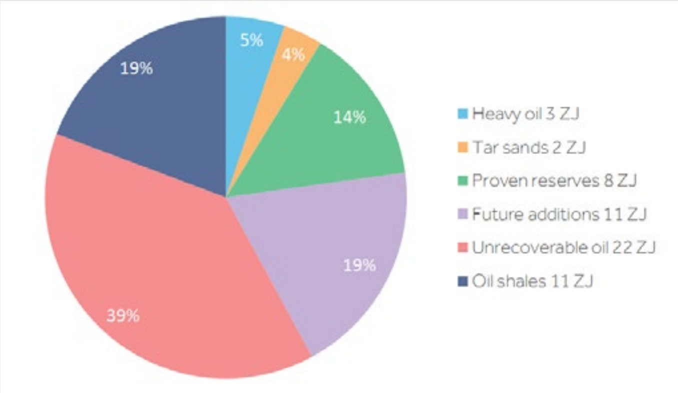


Figure 1-15 Approximate breakdown of the estimated 57 ZJ of oil remaining on the planet

Fuel cell and electric vehicles (EV) do not produce the pollution associated with internal combustion engines. In electric vehicles, fossil fuels are used to generate the electricity needed to recharge the batteries. In fuel cell vehicles, the hydrogen is also typically made from fossil fuels. So how do these types of vehicles benefit us?

If the electricity or hydrogen is produced from fossil fuels, carbon emissions are cut into half. If the electricity or hydrogen is generated from renewable resources such as solar panels and electrolysis, the carbon emissions can be reduced to less than 1%. The cars operated by EV batteries are still cleaner than gas-powered vehicles. In addition, the cost of the electricity required or the hydrogen generated can be only a fraction of the current cost of gasoline per gallon. *Figure 1-16* shows examples of electric and a fuel cell vehicles.

Calculating the carbon emissions from various vehicle types can get complicated, however, there are a couple of easy relations that can be used to compare vehicles and the amount of carbon emissions are:

- where Eg is the gasoline-equivalent energy content of electricity factor,
- 1/0.15 is the fuel content factor,
- AF is the petroleum-based accessory factor, and
- DPF is the driving pattern factor.

This methodology was developed by the United States Department of Energy to compare the fuel economy of electric and hybrid vehicles with traditional gasoline vehicles.

A simple method of calculating vehicle emissions is based upon fuel type. The fuel emission factor is based upon the fuel's heat content, the fraction of carbon in the fuel that is oxidized and the carbon content. This can be calculated as follows [9]:

CO_2 emissions = fuel used x heating value x emission factor

This equation is often used to obtain quick estimates for CO2 emissions.

Figure 1-16

1.5 Innovative Green Technologies

As mentioned in Section 1.1, there are many types of renewable "green" technologies. These technologies include fuel cells, solar cells, wind power and electrolysis.

An introduction to these technologies is described in the next few sections.

1.5.1 Solar Cells

Solar Panel

The Sun has about 6.5 billion years left before it collapses to a white dwarf star, so the heat and the light from the Sun can provide an essentially endless amount of energy. We can harness this energy in many ways, including concentrating solar power systems, passive solar heating and day lighting, photovoltaic systems, solar hot water, solar process heat, and space heating and cooling.

Solar power can be used for both large and small applications. Businesses and industry can diversify their energy sources, improve efficiency, and save money by choosing solar technologies. Home owners can use solar energy for heating and cooling, electricity, and water heating. Home owners can also use solar technologies to produce enough electricity to operate "off-grid" or to sell the extra electricity to the utilities, depending on local programs. There are many solar design strategies that can help both homes and commercial buildings operate more efficiently and make them more pleasant and comfortable places in which to live and work.

Beyond these localized uses of solar power, utilities and power plants are also taking advantage of the sun's abundant energy resource and offering the benefits to their customers. Concentrating solar power systems allow power plants to produce electricity from the sun on a larger scale, which in turn allows consumers to take advantage of solar power without making the investment in personal solar technology systems.

Concentrating solar power systems (CSP)

Systems that use lenses or mirrors and tracking systems to collect a wide array of sunlight into a small beam. The light beam can be used as a heat source for a traditional power plant. There are many types of concentrating technologies, such as the solar trough, solar power tower and the parabolic dish.

1.5.2 Wind Power

Wind turbines use the wind to generate electricity. They are mounted on towers usually 100 feet (30 meters) or more above the ground, where they can take advantage of faster and less turbulent wind. Turbines catch the wind's energy with their propeller-like blades which are mounted on a shaft to form a rotor.

A blade acts much like an airplane wing. When the wind blows, a pocket of low pressure air forms on one side of the blade. The low-pressure air pocket then pulls the blade toward it, causing the rotor to turn. This is called lift. The force of the lift is actually much stronger than the wind's force against the front side of the blade, which is called drag. The combination of lift and drag causes the rotor to spin like a propeller, and the turning shaft spins a generator to make electricity.

Wind turbines can be used as standalone applications such as water pumping or communications, or they can

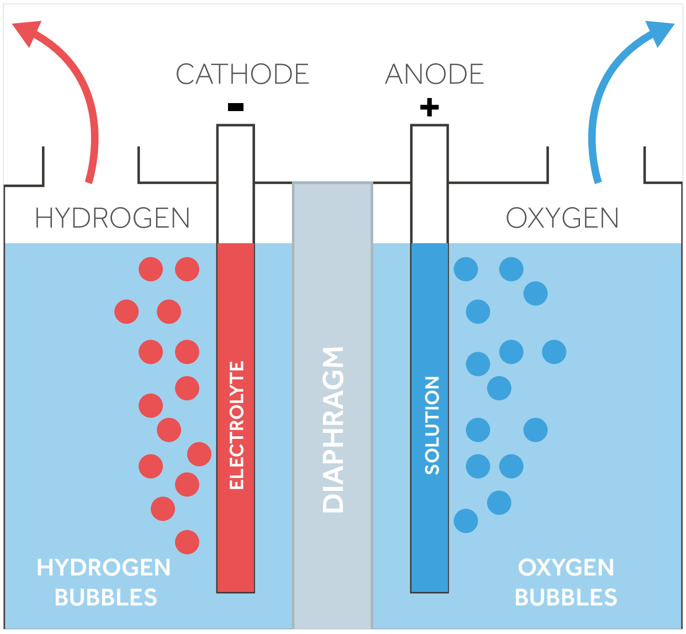
Wind turbines

be connected to a utility power grid or even combined with a photovoltaic (solar cell) system. For utility-scale (megawatt-sized) sources of wind energy, a large number of wind turbines are usually built close together to form a wind farm. Several public electricity providers today use wind farms to supply power to their customers, while homeowners, farmers, and ranchers in windy areas can also use smaller individual wind turbines as a way to cut their electric bills.

1.5.3 Electrolysis

Electrolysis is a chemical reaction that uses an electric current to break the bonds that hold molecules together. An electrolyzer is a machine that can introduce an electric current into a liquid using two pieces of metal called electrodes. The electric current can cause ions to move within compounds, which allows the reaction of electrolysis to take place.

The electrolysis of water is the breaking of the water molecule into hydrogen and oxygen using electricity. The electrolysis of pure water is very difficult since it has a very low conductivity, meaning electricity doesn't want to flow through it very easily. The electrical conductivity can be sped up by adding an electrolyte such as an acid, salt or a base. Salt water has roughly one million times more conductivity than pure fresh water. To start



Standard Electrolysis

an electrolysis reaction, an electrical power source is connected to two electrodes that are placed into water. Hydrogen bubbles will appear at the negatively charged electrode, and oxygen will bubble up at the positively charged electrode. The amount of hydrogen and oxygen generated will depend on the electrical charge that was sent through the water. The electrolysis occurs because energy is required to keep the ions separated in order for them to gather at the different electrodes.

ION

A particle that is electrically-charged (it can be a positive or negative charge), or an atom or molecule that had gained or lost electrons.

1.5.4 Fuel Cells

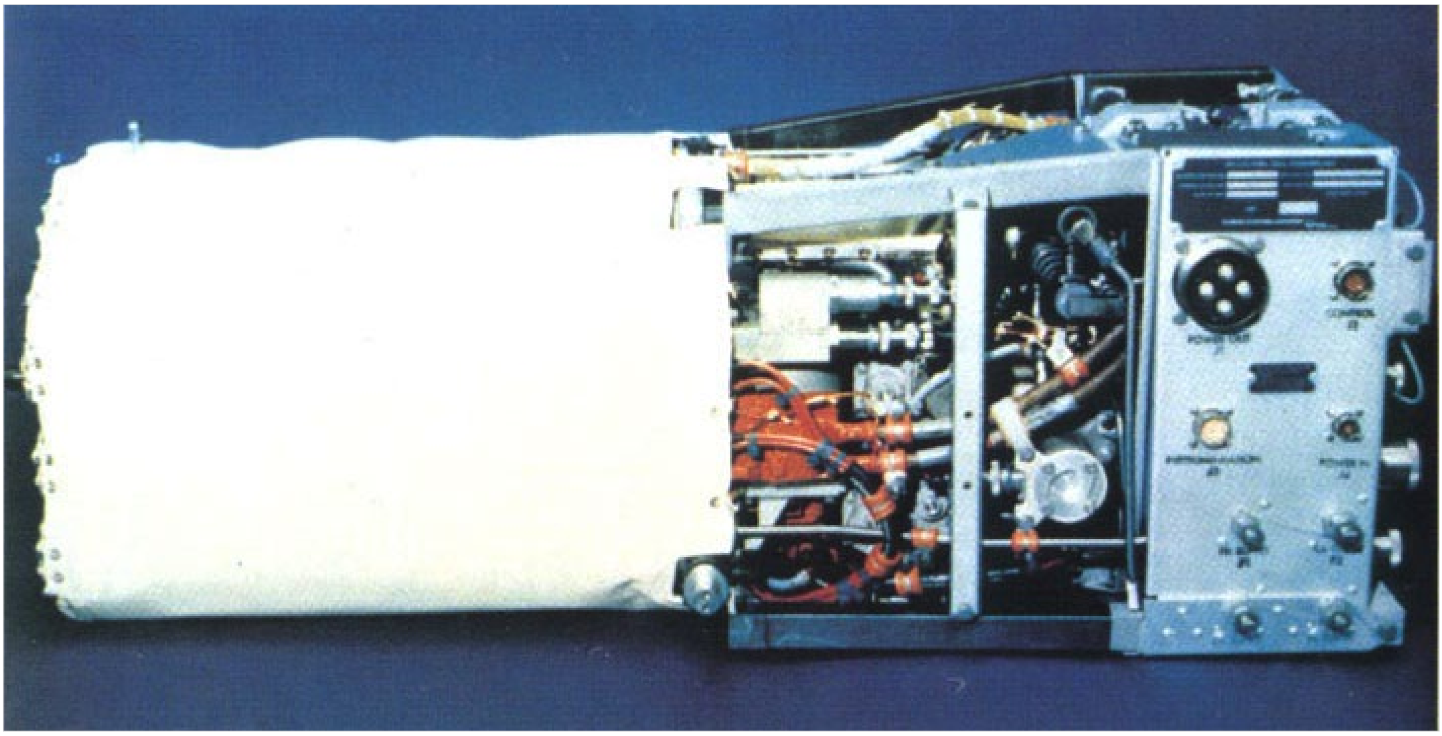


Figure 1-17. NASA fuel cells

Fuel cells convert chemical energy directly into electricity and heat with high efficiency. These devices can be used anywhere at anytime, for as long as necessary as long as fuel is supplied. Fuel cells are one of the few alternative energy devices that can be used for many applications. They can power portable electronics, automobiles, houses, buildings, and even space ships (*Figure 1-17* illustrates NASA fuel cells)! The basic technology behind a fuel cell is simple: it consists of an electrolyte layer sandwiched between a porous anode and cathode on either side.

Anode

The negatively charged terminal of a fuel cell or battery that is supplying current.

Cathode

The positively charged terminal of a fuel cell or battery that is supplying current.

Hydrogen is broken into protons and electrons on the anode side, and is combined with oxygen to produce water and heat on the cathode side. Protons are transported from the anode to the cathode through the electrolyte, and the electrons are carried to the cathode over the external circuit. Both the anode and cathode contain a catalyst to speed up the chemical reactions. *Figure 1-18* shows an example of a typical proton exchange membrane (PEM) fuel cell with the following reactions:

Chemical Reactions Anode:

H2 (g) →2H+ (aq) + 2e–

Cathode:

$\frac{1}{2}\ O_2$ (g) + 2H+ (aq) + 2e– → H_2O (l)

Overall:

H_2 (g) + $\frac{1}{2}\ O_2$ (g) → H_2O (l)

+ electric energy + waste heat

Fuel cells can utilize a variety of fuels to generate power in addition to hydrogen. Chemicals such as phosphoric acid, carbonate, methanol, solid oxides, and ethanol can all be used to power a fuel cell, but the chemical reactions involved is of course different from the one described above. Fuel for many of these types of fuel cell can be made from fossil fuels as well as many sources of biomass, including from municipal wastes, sewage sludge, forestry residues, landfill sites, and agricultural and animal waste.

Though fuel cells are a very efficient and clean source of energy, their power output is relatively small and can sometimes generate a lot of waste heat. Still, they are an important part of the future of energy.

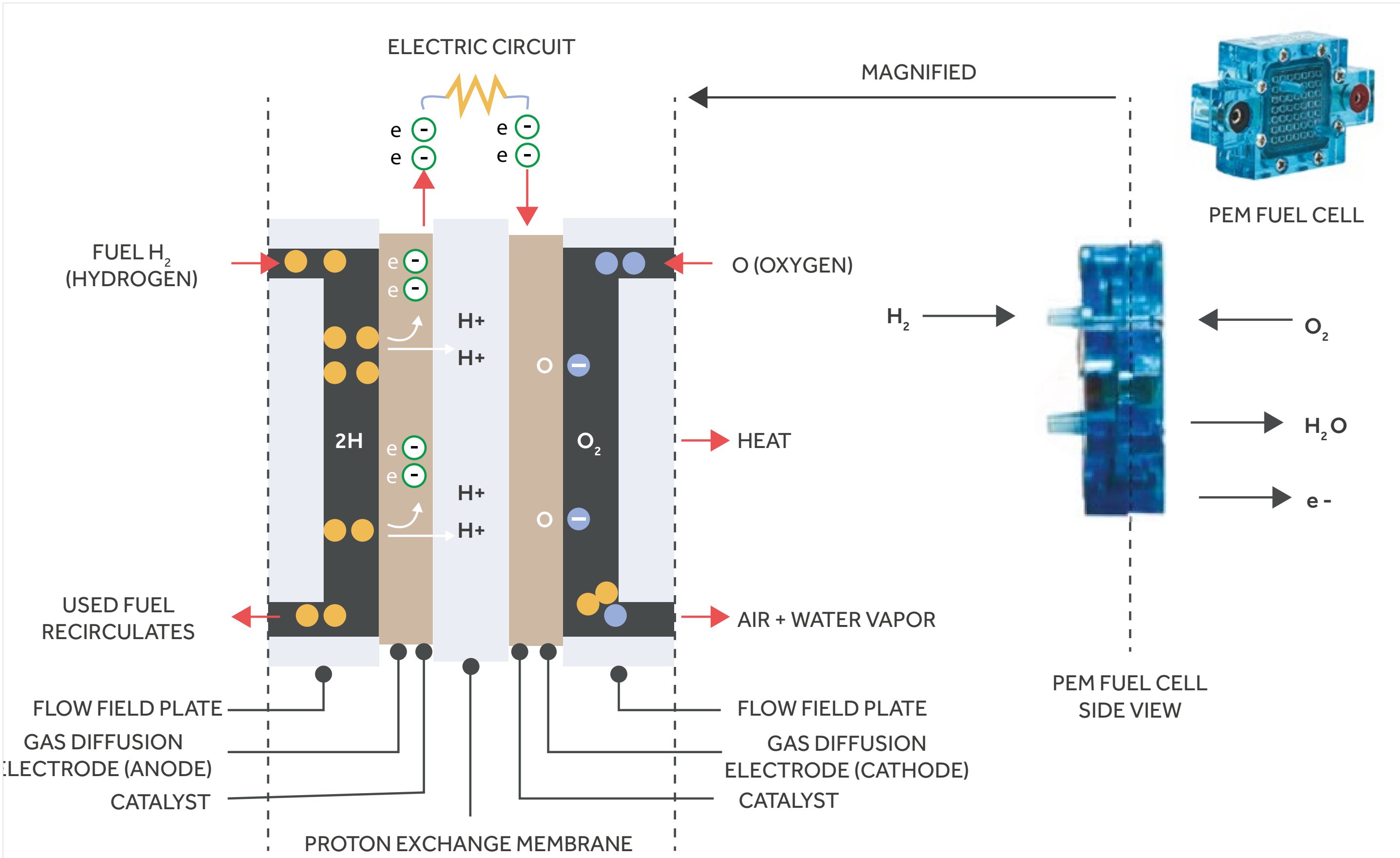


Figure 1-18. A single PEM fuel cell configuration

1.6 Vision of a Hydrogen Clean Energy Economy Based on Renewables in Combination

Fossil fuels – Gas

What if we could replace all of the energy currently generated by polluting fossil fuels with clean, renewable energy that didn't harm the environment and gave us unlimited electricity? Why wouldn't we do it? The answer isn't as easy as it sounds. We depend on fossil fuels not because they pollute but because they're actually really good at what they do. They are easily transported, they can be stored in massive amounts and can be used when needed, and also contain a large amount of energy in every drop.

Fossil fuels have been a part of the world economy for more than a hundred years, and the buildings and infrastructure in place to extract them from the ground, refine them into different products, distribute them to consumers, and burn them to provide energy have been improved and streamlined to the point that the average person doesn't need to even think about them.

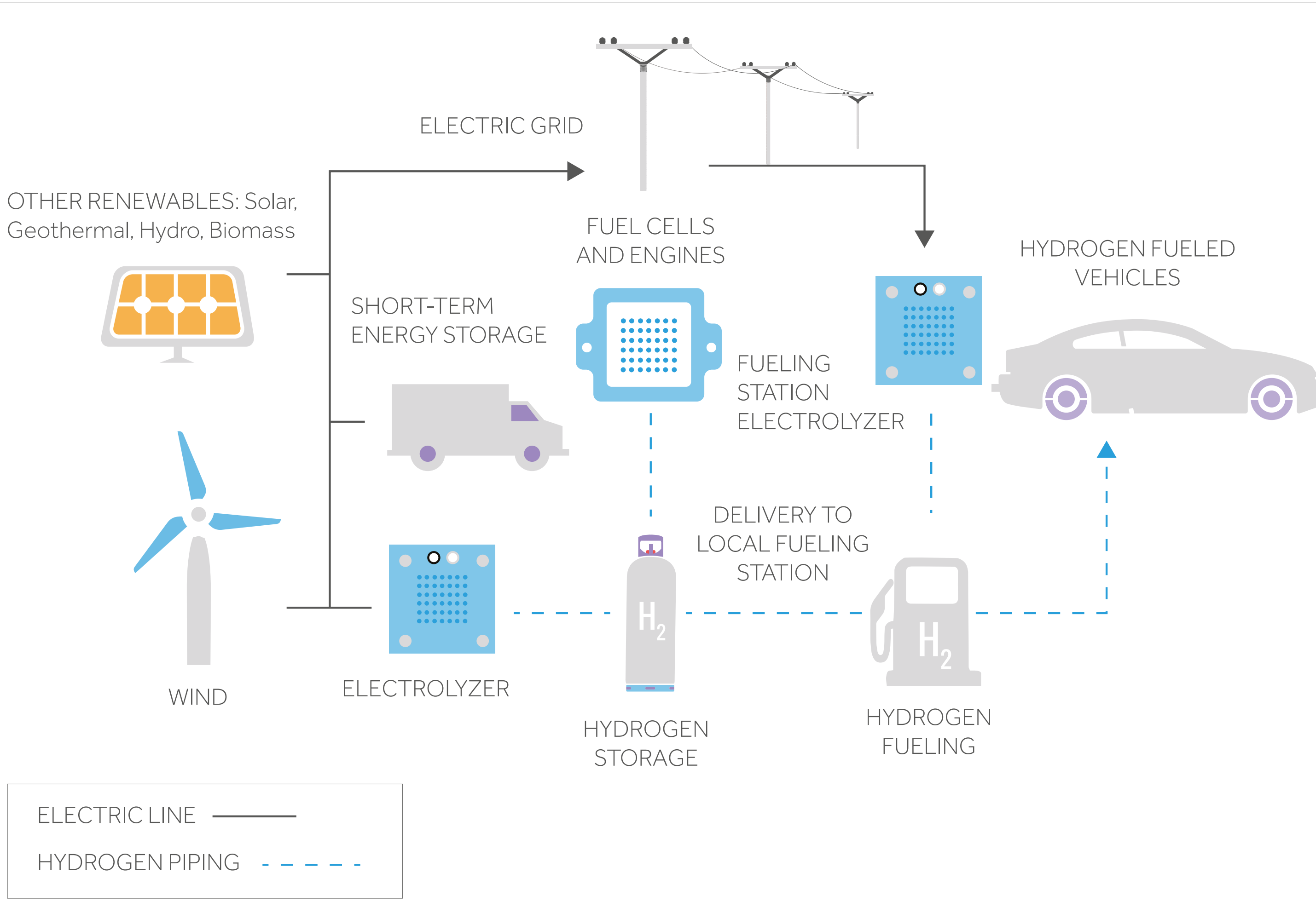


Figure-1-19. A Hydrogen-based Energy System

It's really a remarkable system. To get gasoline into your car, it must be extracted from thousands of feet underground or from the bottom of the ocean floor often halfway around the world, transported over many weeks in massive oil tankers or through pipelines that stretch for hundreds of miles, refined in a delicate chemical process to separate gasoline from the many other oil byproducts, distributed across the country by fleets of tanker trucks, and siphoned into underground storage tanks that can dispense it directly into your car safely and accurately. And a gallon of gas still costs less than a gallon of coffee.

Now imagine that all of this infrastructure, equipment, and manpower was devoted to hydrogen power instead of oil.

Unlike oil, natural gas, and coal, hydrogen is the most abundant element in the universe, and can be extracted from resources that are available all over the world: water, organic matter, and even oil and gas! It also burns cleanly, producing only water as its exhaust. But there are some drawbacks to hydrogen as well. It doesn't exist on its own in nature, so it requires energy to separate it from the other elements with which it naturally bonds. It's also less energy-dense, so there isn't as much power to be gotten from a milliliter of hydrogen as from a milliliter of gasoline. There are ways to get around these shortcomings, and the easiest way is through other sources of renewable energy.

Clean energy such as wind or solar power is a great way to generate electricity without producing any pollution, but the Sun doesn't always shine and the wind doesn't always blow. This is where hydrogen can fit into the energy grid of the future (*Fig. 1-19*). Whenever there's excess energy, that excess can be used to generate hydrogen: from water, biomass, or hydrocarbons. Then when there's a shortage of energy thanks to a cloudy day or a windless night, that hydrogen can be used as fuel for hydrogen fuel cells to generate electricity to fill in the gaps. It's never cloudy or windless everywhere, so hydrogen can be produced in one area even while another is using it.

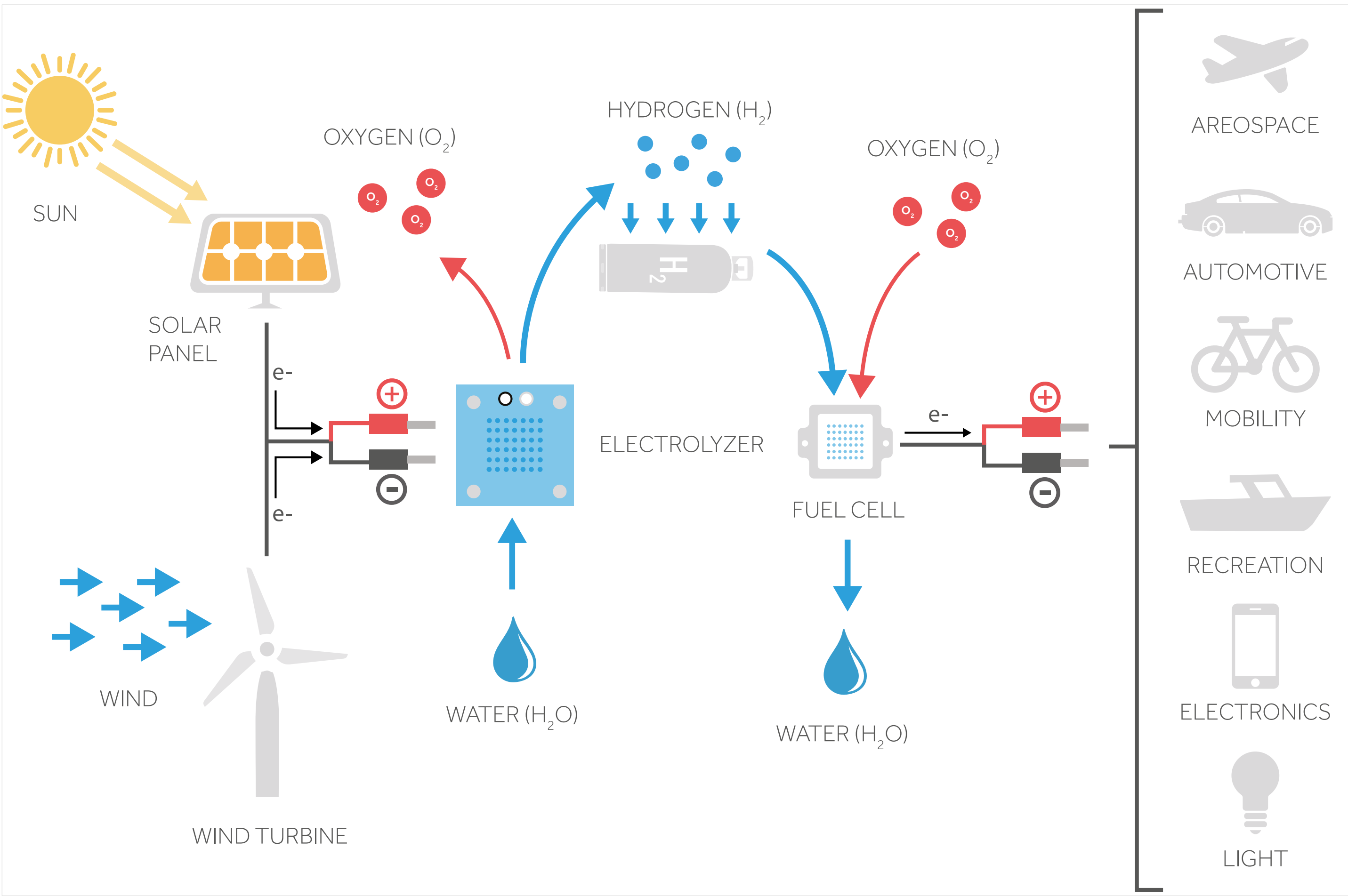


Figure-1-20. Diagram of Renewable Hydrogen Cycle from Renewables to Applications

By making our power grid less dependent on big, centralized power plants and encouraging local generation of power, we also decrease the amount of power needed to transmit electricity over long distances. Excess hydrogen from the power system becomes fuel for our hydrogen cars, which could plug in to provide power to our homes and offices when not using their hydrogen to move.

This is all possible. Maybe, as oil becomes scarce and the technology to make hydrogen fuel cells improves in the future, our economy will be driven by hydrogen and renewable energy, and we'll finally have a source of energy that doesn't damage our planet to power our lives.

1.7 Conclusions

Energy

Energy is a vital part of our modern way of life. While fossil fuels have been the major source of energy for over a hundred years and have helped to spur tremendous growth of our technology, mobility, and nearly every aspect of our lives, they have significant consequences for our world: pollution, global climate change, and the depletion of limited natural resources. To continue to grow and thrive and to protect our environment, we need to outgrow fossil fuels.

Global energy demand will continue to rise as new countries and societies begin to build larger homes and larger cars while the world's population continues to climb beyond 7 billion people. Our limited fossil fuels can't be expected to keep up with this growth, and when they eventually run dry we will need alternative sources of energy to fill our needs.

Luckily, much work has already been done to develop clean, renewable energy sources. Solar power generates electricity from sunlight, wind power harnesses the kinetic energy of the air, bioenergy releases the chemical energy of plants, and hydrogen fuel cells provide power using the most abundant element in the universe. While they each have advantages and disadvantages, they all have the potential to be a central part of our energy infrastructure in the future.

In the next chapters, we will explore these and other sources of power to learn more about how these technologies are already reshaping the energy economy and beginning to drive the next revolution in energy production.

QUIZ

1. Which two nations currently have energy demands that are growing faster than the rest of the world?

a. USA and Canada
b. China and India
c. USA and China
d. Russia and India

2. How does carbon dioxide contribute to global warming?

a. It absorbs infrared radiation
b. It blocks sunlight
c. It comes from fossil fuels
d. It is absorbed by plants

3. All of the following are ways to reduce the impact of global warming EXCEPT:

a. Improving energy efficiency
b. Conserving energy
c. Using zero-carbon energy sources
d. Increasing energy demand

4. Which of these is NOT a disadvantage of fossil fuels?

a. They are a nonrenewable resource
b. They release harmful radiation
c. They cause pollution
d. They contribute to global warming

5. A hydrogen-based clean energy economy would still require:

a. Gasoline-powered cars
b. Coal power plants
c. Solar and wind power
d. Nuclear energy

Science Education Manual Chapter 1:

The Environment and Climate Change

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