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Attributes of Renewable Energy: From Nanopossibilities to Solar Power

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by Kenneth William Spinka

Introduction

While non-renewable energies from stratigraphic extractions that yield hydrocarbon fuels deplete the eon-old planetary geochemistry, renewable energies challenge the sciences for strategic solutions to both energy generation and energy application. The evolutionary mathematics and the revolutionary science that emerge from concepts of replenishable resources enhance classical curriculum-relevant classroom deliveries. This curriculum unit introduces and integrates renewable energy as a sample study subject for the math curriculum and physics curriculum of high-school grade levels within the New Haven Public School system. Selected goals and objectives are cited in the appended lesson plans that will enable students to respond to a series of associated assessments, for Mathematics: Algebra, Calculus, Geometry, and Trigonometry, grades 9-12; and for Science: Physics, grades 11-12.

Consequently, students experiment with alternate solar energy models that compare and contrast the risk-benefit analyses of collecting, storing, distributing, and applying solar energy to create self-sustaining energy plans for environmental equilibrium, hydrocarbon reductions, and real-time energy problem solving. The attributes of solar collector materials and time-lapsed performance patterns harvesting solar energy, storing solar energy, and calculating solar angles, comprise the data that will be popular with math students. Exploring alternative materials implicit to material science, performance specifications for managing and converting the Sun's photons, and the future designs of both active and passive systems, comprise the data that will be most popular with science students. Pedagogical approaches to nanomaterials and nanotechnologies are also presented, demonstrating more flexible, more stable, and higher performing solar energy generator-candidates to power our planet with less costs, smaller dimensions, and a more predictable future.

Historical Perspectives

The Renewable Energy seminar has increased my preparation for courses and curricular areas I am assigned to teach in Mathematics and Physics, relative to the effectiveness and efficiency of renewable energies. Solar energy has been harnessed from the radiant light and heat of the Sun since the ancient times of human development, using a broad range of ever-evolving technologies. The recorded history of solar power and solar technology had a surprising start in the 7 th Century B.C. when glass and mirrors were first focused to concentrate heat from the Sun and light fires. Subsequently, the contemporary powering of buildings and vehicles from solar energy has resulted from a robust history of discovery, experimentation, and implementation. Clearly, a more comprehensive glimpse onto the future is achieved by realizing notable accomplishments in the historical development of solar technology, throughout time and recorded history.

As early as the 7th Century B.C., the magnifying glass had been used to concentrate the sunlight to make fire, similar to the Greeks and Romans who used mirrors to light torches for religious ceremonies in the 3rd Century B.C.. In the year 212 BC, and the 3rd Century B.C., the Greek scientist, Archimedes, used the reflective properties of bronze shields to focus sunlight on and to set fire to wooden ships from the Roman Empire during the Siege of Syracuse. Later, to demonstrate the validity of this claim, the Greek navy re-enacted this feat as an experiment in 1973 and successfully set fire to a wooden boat at a distance of 50 meters. The Chinese were also successful in lighting torches for religious ceremonies as recorded in 20 A.D..

The famous Roman bathhouses in the first to fourth centuries A.D. had large south facing windows to let in the Sun's warmth, as discovered by the Hebrew University of Jerusalem at the Zippori Park archeological sites from the Roman Period, 1st to 4th Century A.D..[1] During the 6th Century A.D., sunrooms on houses and public buildings were so common that the Justinian Code initiated "Sun Rights" to ensure individual access to the Sun. Similarly, the ancestors of Pueblo people, called Anasazi in North America, lived in south-facing cliff dwellings that capture the winter Sun during the 1200s A.D.. Hot Boxes of the 1700s were credited to Swiss scientist Horace de Saussure in 1767 for the world's first solar collector on which Sir John Herschel later cook food during his South African expedition in the 1830s.[2]

On September 27, 1816, Robert Stirling, a minister in the Church of Scotland, applied for a patent at the Chancery in Edinburgh, Scotland for heat engines that he had fabricated. Lord Kelvin used one of the working models during some of his university classes. This engine was later used in the dish/Stirling system, a solar thermal electric technology that concentrates the Sun's thermal energy in order to produce power. Subsequently, the French scientist Edmond Becquerel discovered a photovoltaic effect in 1839, while experimenting with an electrolytic cell made up of two metal electrodes placed in an electricity-conducting solution and that the electricity-generation increased when exposed to light.

The French mathematician August Mouchet developed a concept for solar-powered steam engines in 1860,. In the following two decades, he and his assistant, Abel Pifre, constructed the first solar powered engines for a variety of applications, and they were the predecessors of modern parabolic dish collectors. Willoughby Smith discovered the photoconductivity of selenium in 1873 and in 1876 William Grylls Adams and Richard Evans Day discovered that selenium produces electricity when exposed to light. Although selenium solar cells failed to convert enough sunlight to power electrical equipment, they proved that a solid material could change light into electricity without heat or moving parts.

Samuel P. Langley invented the bolometer in 1880, which was used to measure light from the faintest stars and the heat from that sunlight with a fine wire connected to an electric circuit. When radiation fell on the wire, it became warmer and increased the electrical resistance of the wire. In 1883, Charles Fritts, an American inventor, described the first solar cells made from selenium wafers. Heinrich Hertz discovered that ultraviolet light altered the lowest voltage capable of causing a spark to jump between two metal electrodes. In Baltimore, inventor Clarence Kemp patented the first commercial solar water heater in 1891 at The California Solar Center.]3]

Wilhelm Hallwachs discovered that combinations of copper and cuprous oxide are photosensitive in 1904, while Albert Einstein published his paper on the photoelectric effect in 1905, with a paper on his famous theory of relativity. William J. Bailley of the Carnegie Steel Company develops a solar collector with copper coils and an insulated box in 1908, and very similar to the current design, and by 1914 the importance of barrier layers in photovoltaic devices was recognized. By 1916, Robert Millikan provided experimental proof of that photoelectric effect and Polish scientist Jan Czochralski developed a way to grow single-crystal silicon. [4] Albert Einstein won the Nobel Prize in 1921 for his theories that explain the photoelectric effect as published in his 1904research and technical paper. The photovoltaic effect in cadmium sulfide (CdS) was discovered in 1932 by Audobert and Stora.

By 1947, the popularity of passive solar architecture in the United States rose as a result of scarce energy during the prolonged WW2, that Libbey-Owens-Ford Glass Company published a book entitled Your Solar House that profiled forty-nine of the nation's greatest solar architects.[5] Dr. Dan Trivich, Wayne State University, makes the first theoretical calculations of the efficiencies of various materials of different band gap widths based on the spectrum of the Sun in 1953. The following year, 1954, marked the beginning of photovoltaic technology in the United States when Daryl Chapin, Calvin Fuller, and Gerald Pearson develop the silicon photovoltaic (PV) cell at Bell Labs as the first solar cell capable of converting enough solar energy to power everyday electrical equipment.

Bell Telephone Laboratories produced a silicon solar cell with 4% efficiency and later achieved 11% efficiency.[6] Then in 1955, Western Electric sold commercial licenses for silicon photovoltaic (PV) technologies. Early successful products included PV-powered dollar bill changers and devices that decoded computer punch cards and tape. In 1955, architect Frank Bridgers designed the world's first commercial office building using solar water heating and passive design, the Bridgers-Paxton Building, which has been continuously operating since that time and is now in the National Historic Register as the world's first solar heated office building. William Cherry, U.S. Signal Corps Laboratories, approached RCA Labs' Paul Rappaport and Joseph Loferski in 1956 about developing photovoltaic cells for the proposed orbiting Earth satellites.

Hoffman Electronics achieved 8 percent efficiency from one version of photovoltaic cells in 1957, and 9 percent efficiency from an improved version of photovoltaic cells in 1958. Also in1958, T. Mandelkorn, U.S. Signal Corps Laboratories, fabricated n-on-p silicon photovoltaic cells, which would prove to be critically important for space cells because of a greater resistance to radiation. During that same year, 1958, the Vanguard I space satellite used a small array of photovoltaic cells of less than one watt for radio power. Later that year, Explorer III, Vanguard II, and Sputnik-3 were launched with PV-powered systems on board. Despite unsuccessful attempts to commercialize the silicon solar cell in the 1950s and 19660s, powering satellites was always successful. Solar power became the accepted energy source for space applications.[7] Then in 1959, Hoffman Electronics achieved 10 percent efficiency from commercially available photovoltaic cells and added grid contacts to reduce the series resistance significantly.

On August 7, 1959, the Explorer VI satellite was launched with a photovoltaic array of 9600 cells, measuring 1 cm x 2 cm each, followed by the Explorer VII satellite launching on October 13, 1959. By 1960, Hoffman Electronics achieved 14 percent efficiency with photovoltaic cells and Silicon Sensors, Inc., of Dodgeville, Wisconsin, was founded and started producing selenium and silicon photovoltaic cells.[8] Bell Telephone Laboratories launched the first telecommunications satellite in 1962 called the Telstar and initially powered by 14 watts derived from a P-V system. The Sharp Corporation succeeds in producing practical silicon photovoltaic modules in 1963 and Japan installs a 242-watt, photovoltaic array on a lighthouse, and the world's largest array at that time. NASA launches the first Nimbus spacecraft in 1964, which was a satellite powered by a 470-watt photovoltaic array.[9]

Peter Glaser conceives the idea of the satellite solar power station in the DOE's reference brief "Solar Power Satellites." [10] NASA launches the first Orbiting Astronomical Observatory in 1966, powered by a 1-kilowatt photovoltaic array, to provide astronomical data in the ultraviolet and X-ray wavelengths filtered out by the atmosphere. In 1969, the Odeillo solar furnace, located in Odeillo, France was fabricated, featuring an 8-story parabolic mirror. By 1970, Dr. Elliot Berman, with the Exxon Corporation, designed a significantly less costly solar cell, reducing the price from $100 a watt to $20 a watt. Solar cells began to power navigation warning lights and horns on many offshore gas and oil rigs, lighthouses, railroad crossings and domestic solar applications were appearing more feasible in locations remote from a grid-connection.

A cadmium sulfide (CdS) photovoltaic system is installed to operate an educational television at a village school in Niger in 1972. The Institute of Energy Conversion was also established in 1972 at the University of Delaware to perform research and development on thin-film photovoltaic (PV) and solar thermal systems, becoming the world's first laboratory dedicated to PV research and development. The University of Delaware built "Solar One" in 1973, one of the world's first photovoltaic (PV) powered residences. The system is a PV/thermal hybrid. The roof-integrated arrays fed surplus power through a special meter to the electric company during the day and purchased power from the electric company at night. In addition to electricity, the arrays acted as flat-plate thermal collectors, with fans blowing the warm air from over the array to phase-change heat-storage bins.

The NASA Lewis Research Center installed 83 photovoltaic power systems on all continents except Australia in 1976. These systems support diverse applications: as vaccine refrigeration, , and classroom television, grain milling, , medical clinic lighting, room lighting, telecommunications, water pumping, and vaccine refrigeration. At that time, David Carlson and Christopher Wronski, of RCA Laboratories, fabricated the first amorphous silicon photovoltaic cells. A year later in 1977, the U.S. Department of Energy launches a federal facility dedicated to harnessing power from the Sun, the Solar Energy Research Institute named "National Renewable Energy Laboratory."[10] The cumulative global photovoltaic production capacity had exceeded 500 kilowatts in 1977. NASA's Lewis Research Center dedicated a 3.5-kilowatt photovoltaic (PV) system in 1978, when it was installed on the Papago Indian Reservation located in southern Arizona as the world's first village PV system. This system provided for water pumping and residential electricity in 15 homes until 1983, when grid-connections from the power utilities reached the village. The PV system was then dedicated exclusively to pumping water from a community well.

In 1980, ARCO Solar became the first company to produce more than 1 megawatt of photovoltaic modules in one year. At the University of Delaware, the first thin-film solar cell exceeds 10% efficiency with copper sulfide/cadmium sulfide. Paul MacCready built the first solar-powered aircraft in 1981, the Solar Challenger, and flew from France to England across the English Channel. The aircraft had over 16,000 solar cells mounted on its wings, which produced 3,000 watts of power.[11] The first photovoltaic megawatt-scale power station connected on-line in Hisperia, California in 1982, with a 1-megawatt capacity system, developed by ARCO

Solar, with modules on 108 dual-axis trackers. Australian Hans Tholstrup drove the first solar-powered car, the Quiet Achiever, almost 2,800 miles between Sydney and Perth in 20 days, 10 days faster than the first gasoline-powered car.[12] The U.S. Department of Energy, along with an industry consortium, began operating Solar One, a 10-megawatt central-receiver demonstration project.

The project established the feasibility of power-tower systems, a solar-thermal electric or concentrating solar power technology. In 1988, the final year of operation, the system could be dispatched 96 percent of the time.[10] [13] Volkswagen of Germany began testing photovoltaic arrays mounted on the roofs of Dasher station wagons, generating 160 watts for the ignition system. The Florida Solar Energy Center began supporting the U.S. Department of Energy's photovoltaics program in the application of systems engineering and worldwide photovoltaic production exceeded 9.3 megawatts.[14] In 1983, ARCO Solar dedicated a 6-megawatt photovoltaic substation in central California. The 120-acre, unmanned facility supplied the Pacific Gas & Electric Company's utility grid with enough power for 2,000-2,500 homes. Solar Design Associates constructed an independent, 4-kilowatt powered home in the Hudson River Valley, and worldwide photovoltaic production exceeded 21.3 megawatts with sales of more than $250 million.

The Sacramento Municipal Utility District commissioned its first 1-megawatt photovoltaic electricity generating facility in 1984. The next year, 1985, the University of South Wales breaks the 20 percent efficiency barrier for silicon solar cells in accordance with the PV cell calibration of 1-Sun conditions, a total irradiance of 1 Sun or 1000 W/m^2. The world's then largest solar thermal facility, located in Kramer Junction, California, was commissioned in 1986. The solar field contained rows of mirrors that concentrated the Sun's energy onto a system of pipes circulating a heat transfer fluid. The heat transfer fluid was used to produce steam, which powered a conventional turbine to generate electricity. ARCO Solar releases the G-4000--the world's first commercial thin-film power module. Dr. Alvin Marks received patents in 1988 for two solar power technologies he developed: Lepcon and Lumeloid. Lepcon consists of glass panels covered with a vast array of millions of aluminum or copper strips, each less than a micron or thousandth of a millimeter wide.

As sunlight hits the metal strips, the energy in the light was transferred to electrons in the metal that escape at one end in the form of electricity. Lumeloid used a similar approach but substituted cheaper, film sheets of plastic for the glass panels and covered the plastic with conductive polymers, or long chains of molecular plastic units. In 1991, President George Bush re-designated the U.S. Department of Energy's Solar Energy Research Institute as the National Renewable Energy Laboratory. The following year, 1992, the University of South Florida developed a 15.9 percent efficient thin-film photovoltaic cell made of cadmium telluride, breaking the 15 percent barrier for this technology. A 7.5-kilowatt prototype dish system using an advanced stretched-membrane concentrator becomes operational. Pacific Gas & Electric completed installation of the first grid-supported photovoltaic system in 1993 at Kerman, California. The 500-kilowatt system was the first "distributed power" effort. The next year, 1994, the National Renewable Energy Laboratory (formerly the Solar Energy Research Institute) completed construction of a Solar Energy Research Facility that was recognized as the most energy-efficient of all U.S. government buildings. The solar electric system was companion to a passive solar design. Subsequently, a solar dish generator using a free-piston Stirling engine was connected to an electric utility grid. The National Renewable Energy Laboratory developed a solar cell, made from gallium indium phosphide and gallium arsenide that becomes the first one to exceed the 30 percent conversion efficiency barrier. In 1996, the world's most advanced solar-powered airplane, the Icare, flew over Germany. The wings and tail surfaces of the Icare are covered by 3,000 super-efficient solar cells, with a total area of 21 m^2.[15] The U.S. Department of Energy, along with an industry consortium, began operating Solar Two, an upgrade of Solar One, concentrating on the solar power tower project. Operated until 1999, Solar Two demonstrated how solar energy can be stored efficiently and economically so that power can be distributed when sunlight is compromised.[13] The remote-controlled, solar-powered aircraft, "Pathfinder" sets an altitude record, 80,000 feet, on its 39th consecutive flight on August 6,1998, in Monrovia, California. This altitude is higher than any prop-driven aircraft thus far. Subhendu Guha, a noted scientist for his pioneering work in amorphous silicon, led the invention of flexible solar shingles, a roofing material and state-of-the-art technology for converting sunlight to electricity. In 1999, Construction was completed on 4 Times Square, the tallest skyscraper built during the 1990s in New York City, and incorporated more energy-efficient building techniques than any other commercial skyscraper and also includes building-integrated photovoltaic (BIPV) panels on the 37th through 43rd floors on the south and west-facing facades that generate a portion of the buildings power.

Spectrolab, Inc. and the National Renewable Energy Laboratory fabricated a photovoltaic solar cell in 1999 that converted over 32 percent of the available sunlight into electricity. This high conversion efficiency was achieved by layering three photovoltaic materials into one solar cell, which performed most efficiently when received sunlight was concentrated 50 times. To use these cells in practical applications, the cell is mounted in a device with lenses and/or mirrors to concentrate sunlight onto the cell and these "concentrator" systems are mounted on tracking systems that keep them pointed toward the Sun. Later that year, the National Renewable Energy Laboratory achieved a new efficiency record for thin-film photovoltaic solar cells. Their record setting 18.8 percent efficiency for a prototype solar cell out-performed the previous record by more than 1 percent. By the end of the 20th century, the cumulative global photovoltaic production capacity had reached 1000 megawatts. First Solar began production in the year 2000 at Perrysburg, Ohio, the world's largest photovoltaic manufacturing plant with an estimated capacity of producing enough solar panels each year to generate 100 megawatts of power.

At the International Space Station, astronauts installed solar panels on what would be the largest solar power array deployed in space. Each array section was comprised of 32,800 solar cells. Sandia National Laboratories developed an inverter for solar electric systems that increases the safety of the systems during a power outage. Inverters convert the direct current (DC) electrical output from solar systems into alternating current (AC), which is the grid-connection electrical current standard. Two new thin-film solar modules, developed by BP Solarex, break previous performance records. The company's 0.5-square-meter module achieves 10.8 % conversion efficiency, the highest in the world for thin-film modules of its kind. And its 0.9-square-meter module achieved 10.6% conversion efficiency and a power output of 91.5 watts is the highest power output for any thin-film module in the world. In Morrison, Colorado, a 12-kilowatt solar electric system, the largest residential installation in the United States, was registered with the U.S. Department of Energy's "Million Solar Roofs" program.[16]

The system provides most of the electricity for the 6,000-square-foot home and family of eight. Home Depot started selling residential solar power systems in three of its stores in San Diego, California during 2001, and a year later sales expanded to 61 other stores nationwide. NASA's solar-powered aircraft, Helios, set a world record for non-rocket-powered aircraft: 96,863 feet, more than 18 miles high. The National Space Development Agency of Japan, or NASDA, announced plans to develop a satellite-based solar power system that would beam energy back to Earth. A satellite carrying large solar panels would transmit the power with a laser to an airship at an altitude of about 12 miles that would then transmit the power to Earth.

TerraSun LLC developed a unique method of using holographic films to concentrate sunlight onto a solar cell, typically achieved with Fresnel lenses or mirrors to concentrate sunlight. TerraSun demonstrated that the use of holographic optics allows more selective use of the sunlight, allowing light not needed for power production to pass through the transparent modules. This capability allows solar modules to be integrated into buildings as functional skylights. PowerLight Corporation connected the world's largest hybrid system that combines the power from both wind and solar energy online in Hawaii. The grid-connected system is unique because the solar energy capacity of 175 kilowatts exceeds the wind energy capacity of 50 kilowatts. Hybrid power systems combine the merits of both energy systems to maximize available power. British Petroleum (BP) and BP Solar announced the opening of a service station in Indianapolis that features a solar-electric canopy. The Indianapolis station is the first U.S. "BP Connect" store, a model that BP intends to use for all new or significantly renovated BP service stations. The canopy was constructed from translucent photovoltaic modules made of thin films of silicon deposited onto glass.

In 2002, NASA successfully conducted two tests of a solar-powered, remote-controlled aircraft named Pathfinder Plus. While the first test in July enabled researchers to demonstrate the aircraft as a high-altitude platform for telecommunications technologies, the second test in September, demonstrated an aerial imaging system for coffee growers. Union Pacific Railroad installed 350 blue-signal rail yard lanterns that incorporate energy saving light-emitting diode (LED) technology with solar cells, at North Platt, Nebraska, and at the largest rail yard in the United States. ATS Automation Tooling Systems Inc. in Canada commercialized an innovative method of producing solar cells, called Spheral Solar technology. The technology bonds silicon beads between two sheets of aluminum foil and assures lower costs because of reduced use of silicon relative to conventional multicrystalline silicon solar cells. This technology was previously championed by Texas Instruments (TI) in the early 1990s however, despite U.S. Department of Energy (DOE) funding, TI abandoned the initiative.[10] The 38.7-kilowatt White Bluffs Solar Station went online at Richland, Washington followed by one the largest rooftop solar power systems in the United States installed by the PowerLight Corporation during 2002, a 1.18 megawatt system, at the Santa Rita Jail in Dublin, California.

Future expectations concur that all buildings should be constructed to combine energy-efficient design and construction practices and renewable energy technologies for a net-zero energy building. In theory, any building should conserve enough and produce its own energy supply to create a new generation of cost-effective buildings that have zero net annual need for non-renewable energy. Photovoltaics research and development is experimenting with alternative materials, cell designs, and strategic approaches to the production of solar power. Every surface that is exposed to the Sun, from the fabrics worn as clothing to the rigid materials that enclose buildings and vehicles, can contribute to the production of power that is clean and safe.

Future Perspectives

Technology planning for the future outlines the research and development challenge to full competitiveness of concentrating solar power (CSP) with conventional power generation technologies within a decade. The potential of solar power in the Southwest United States is comparable in scale to the hydropower resource of the Northwest. Specifically, a desert area 10 miles by 15 miles could provide 20,000 megawatts of power, while the electricity needs of the entire United States could theoretically be met by a photovoltaic array within an area 100 miles square. Concentrating solar power, or solar thermal electricity, should harness the sun's heat energy to provide large-scale, domestically secure, and environmentally safe electricity.

The price of photovoltaic power should also be competitive with traditional sources of electricity as the technology improves, and solar electricity is additionally used to electrolyze water, producing hydrogen for fuel cells for transportation and buildings. Solar radiation, along with secondary solar-powered resources such as wind and wave power, hydroelectricity and biomass, accounts for most of the available renewable energy on earth. Only a fraction of the available solar energy is being harvested to fulfill planetary energy requirements.

Solar powered electrical generation relies on heat engines and photovoltaic collectors. Solar energy's uses are limited only by human ingenuity. Solar energy applications include: space heating and cooling through solar architecture, potable water via distillation and disinfection, day lighting, solar hot water, solar cooking, and high temperature process heat for industrial purposes. To harvest the solar energy, the most common methods are active and passive solar panel collectors. Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of solar thermal collectors (image 01) and photovoltaic panels (image 02) to generate or collect energy as heat or electricity, respectively whereas passive solar techniques include orienting a building to the Sun, selecting materials with high thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

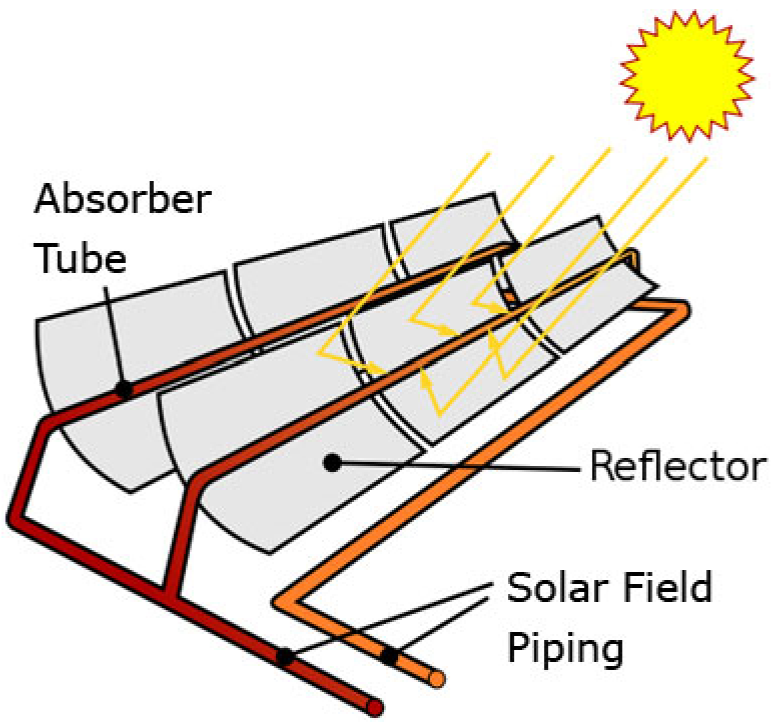

Image 01: Solar Thermal Collectors

Image 02: Photovoltaic Panels

Teaching Perspectives

Experimenting with solar energy will also deliver results that are quantifiable with traditional mathematics including: Algebra, Geometry, Trigonometry and Calculus. These calculations are significant when transitioning from one source of energy to another, since it is important to improve that which is above the earth's crust by not altering that which is below the earth's crust. These calculations become critically meaningful when renewable energy renews at rates that vary from yearto-year, such as when the atmosphere blocks sunlight and reduces the solar energy potential. Congruently, the development of renewable energy and energy efficiency marks "...a new era of energy exploration" in the United States, according to President Barack Obama. In a joint address to the Congress on February 24, 2009, President Obama called for doubling renewable energy within the next three years. New government spending, new regulations and new policies enabled conceivable sustainable production of renewable energy to endure the 2009 economic challenges better than other energy sectors.

This curriculum unit is intended to assist in teaching about the seminar subject in high school classrooms. Mathematics and Physics introduce a variety of equations for both growth and decay that require familiar, popular and tangible examples or models to be successfully taught and learned. Renewable energy is generated from natural resource models such as sunlight, wind, rain, tides, and geothermal heat, which are renewable, naturally replenished, and familiar. The share of global energy consumption and generation of electricity from renewables totals 18% from traditional biomass, such as wood-burning and hydroelectricity, and new renewables that include small hydro, modern biomass, wind, solar, geothermal, and biofuels [4]. Wind power contributes a worldwide capacity of 121,000 megawatts (MW), and is widely used in European countries and the United States.[4] The annual manufacturing output of the photovoltaics industry has reached 6,900 MW, and photovoltaic (PV) power stations are popular in Germany and Spain.[5] Solar thermal power stations operate in the U.S.A. and Spain, and the largest of these is the 354 MW SEGS power plant in the Mojave Desert. [5]

Counterpoint

Although the world's largest geothermal power installation is The Geysers in California with a rated capacity of 750 MW, Brazil has one of the largest renewable energy programs in the world, involving production of ethanol fuel from sugar cane that provides automotive fuel.[18] Ethanol fuel is also widely available in the United States. While most renewable energy projects are large-scale, renewable technologies are also adapted to smaller off-grid applications. Kenya, for example, is a world leader in household solar ownership, installing approximately 30,000 small (20100 watt) solar power systems per year.[19] Some renewable energy technologies are scrutinized for intermittent deliveries or unsightly systems however, the renewable energy market and popularity continue to grow because of climate change concerns and high oil prices. Consequently, the renewable energy industry is the recipient of increasing government support, new legislation, incentives and commercialization, making this curriculum unit a real-time resource for mathematics-based demonstrations.

Lesson Plans

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1. active solar techniques

   a. orientation with respect to solar sources
   b. photovoltaic panels with distribution
   c. photovoltaic panels with storage
   d. solar thermal collectors with distribution
   e. solar thermal collectors with storage

2. passive solar techniques

   a. orientation with respect to solar sources
   b. thermal-absorbing by material
   c. thermal-retaining by mass

d. light or thermal dispersing properties

If the amount of sunlight that actually strikes the earth is considered, conservative assumptions would conclude that there is a lot of land exposed to the Sun and available for collecting sunlight. Estimating that every square yard of land exposed will receive an average of 5 kW-hours of solar energy per day [20], an area covering 100 square yards would generate 500 kW-hours per day. Comparatively, the average household in the United States consumes 500-1000 kW-hours of electrical energy in one month [18], as quantified in a typical energy bill. Consequently, if energy from the Sun were harnessed efficiently and effectively, there should be limitless energy resources to accommodate those demand requirements. Nanotechnology factors into this real-time equation. One nanomaterial of particular interest is titanium dioxide which, when combined with a special dye, will absorb solar energy and convert that energy into electrical energy.[18] The general aspiration and motivation is that these photovoltaic cells will be more efficient due to nanotechnologies, cost less to produce due to nanomaterials, and have significantly less affect on the environment than typical solar cells due to nanoscalar dimensions.

Essential Questions

As students select and use appropriate units and instruments for measurement to achieve the degree of precision and accuracy required in real-world situations, they also understand and use the tools of data analysis for managing information. Each student describes, analyzes, and generalizes a wide variety of patterns, relations, and functions. Each student uses the scientific processes and habits of mind to solve problems. Each student understands that all matter has observable, measurable properties. Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together. Atoms interact with one another by transferring or sharing electrons that are furthest from the nucleus.

These outer electrons govern the chemical properties of the element. Chemical reactions may release or consume energy. Some reactions such as the burning of fossil fuels release large amounts of energy by losing heat and by emitting light. Light can initiate many chemical reactions such as photosynthesis and the evolution of urban smog. Reactions involve electron transfer. A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions, molecules, or atoms. In other reactions, chemical bonds are broken by heat or light to form very reactive radicals with electrons ready to form new bonds. Radical reactions control many processes such as the presence of ozone and greenhouse gases in the atmosphere, burning and processing of fossil fuels, the formation of polymers, and explosions. Catalysts accelerate chemical reactions. Catalysts, such as metal surfaces, accelerate chemical reactions. Chemical reactions in living systems are catalyzed by protein molecules called enzymes.

Experiments determine that the rates of reaction among atoms and molecules depend on the concentration, pressure, and temperature of the reactants and the presence of catalysts. Each Student understands that the total energy in the universe is constant. Energy can be transferred by collisions in chemical and nuclear reactions, by light waves and other radiations, and in many other ways. However, it can never be destroyed. As these transfers occur, the matter involved becomes steadily less ordered. All energy is either kinetic or potential. All energy can be considered to be either kinetic energy, which is the energy of motion, potential energy, which depends on relative position, or energy contained by a field, such as electromagnetic waves.

Energy is quantized. Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit light only at wavelengths corresponding to these amounts. These wavelengths can be used to identify the substance. Electrons flow in materials and, in some materials such as metals, electrons flow easily, whereas, in insulating materials such as glass, they can hardly flow at all. Semiconducting materials have intermediate behavior. At low temperatures, some materials become superconductors and offer no resistance to the flow of electrons. The term for the amount of energy produced by the Sun over a specific area is solar irradiation and it is usually expressed in terms of watts per square meter (Watts/m ^{2}). One of the ways you can measure this energy is through special instruments called pyranometers or pyrheliometers. A pyranometer measures the Sun's radiation and any extra radiation that has been scattered by particles in the sky. A pyrheliometer measures the direct Sun's radiation. In one project, you will make a pyranometer and pyrheliometer by using a solar cell. You will connect the cell to something that measures current such as a millameter or voltmeter. The first step in understanding solar irradiation begins with understanding the Sun. The Sun is a sphere of intensely hot gasses that is about 150 million kilometers from Earth.[18] The temperature on the Sun ranges from about 5,700 degrees Celsius at the surface to an estimated 14 million degrees Celsius in the center.[18]The amount of energy that reaches earth is an extremely small fraction, only about one-billionth of the energy on the Sun.[20]

IMPLEMENTATION DESIGN: Design For Instructional Table				
Instruction	Objectives	Resources	Schedule	Assessment
Photovoltaic capacities of nanotitania.	Solar Cells.	Dye Electrolyte Electrodes Vernier Pro Logger Voltage/Current Probe	One week	Solar Energy quiz

Lesson Plan for Nanofabrication of Solar Cells [26]:

Nanotitania synthesis: The Preparation

1. Add 100-ml of anhydrous isopropanol [$(CH_3)_2CHOH$] to 2-ml of 2,4-pentanedione ($C_5H_8O_2$) and stir covered for 20 minutes.
2. Add 6.04-ml of titanium isopropoxide ($Ti[(CH_3)_2CHO]_4$ to the solution and stir for 3 hours.
3. Add 2.88-ml of distilled water and stir for another 2 hours.
4. The solution must then age for 12 hours, as the powder will precipitate out of solution at room temperature.
5. The remaining liquid should be decanted and the precipitate should be allowed to dry.

6. If you have access to X-ray diffraction, and some crystals on a slide, or a scanning electron microscope with an EDX device, analysis will provide identification. This will determine whether the product is titanium dioxide.

Nanocrystalline Solar Cells: The Materials

1. (2) F-SnO_2 glass slides
2. Iodine and potassium iodide
3. Mortar and pestle
4. Air gun
5. Surfactant (Triton X-100 or dish washing detergent)
6. Colloidal titanium dioxide powder
7. Nitric acid
8. Blackberries, raspberries, citrus leaves
9. Masking tape
10. Tweezers
11. Filter paper
12. Binder clips
13. Various glassware
14. Multi-meter

The photovoltaic cell has basically four main parts.

1. Nanolayer (nanotitania suspension)
2. Dye
3. Electrolyte
4. 2 electrodes

The nanolayer is the nanotitania. The dye can be juice extracted from raspberries, blackberries, or citrus leaves. The electrolyte is a solution of iodine/iodide. The two electrodes are conductive glass slides that have been coated with fluorine-doped tin oxide.

Preparation of the Electrolyte

1. Measure out 10-ml of ethylene glycol.

2. Weigh out 0.127-g of I_2 and add it to the ethylene glycol and stir.
3. Weigh out 0.83 g of KI and add it to the same ethylene glycol.
4. Stir and sore in a container with a tight lid. This container should also be dark to retard light transmission through the glass.

Preparation of the Dye

1. Crush 5-6 berries in a mortar and pestle with 2-ml of deionized water.
2. Filter the solution with a coffee filter or any type of paper towel.

Preparation of the Nanotitania Suspension

1. Add 9 ml (in 1 ml increments) of nitric or acetic acid (pH 3-4) to six grams titanium dioxide in a mortar and pestle.
2. Grinding for 30 minutes will produce a lump free paste.
3. 1 drop of a surfactant is then added (Triton X-100 or dish washing detergent).
4. The suspension is then stored and allowed to equilibrate for 15 minutes.

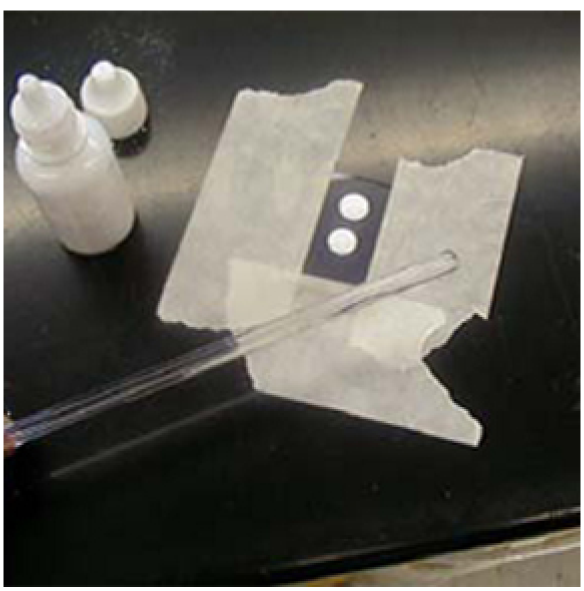

Image 03: forming a tape mold w/sample on a slide

Cell Fabrication Procedure

1. After testing with a multimeter to determine which side is conductive, one of the glass slides is then masked off 1-2 mm on THREE sides with masking tape (Image 03). This is to form a mold.
2. A couple of drops if the titanium dioxide suspension is then added and distributed across the area of the mold with a glass rod.
3. The slide is then set aside to dry for one minute.
4. After the first slide has dried the tape can be removed.
5. The titanium dioxide layer needs to be heat sintered using a hot air gun that can reach a temperature of at least 450 degrees Celsius.
6. This heating process should last 30 minutes.
7. Allow the heat sintered slide to cool to room temperature.
8. Once the slide has cooled, place the slide face down in the filtered dye and allow the dye to be absorbed for 5 or more minutes (image 04).
9. After the first slide has absorbed the dye, it is quickly rinsed with ethanol to remove any water and blotted dry with tissue paper.
10. The two slides are then placed quickly in an offset manner together so that the layers are touching.
11. Binder clips hold both slides together (image 05).
12. One drop of a liquid iodide/iodine solution is then added. Capillary action will stain the entire inside of the slides.

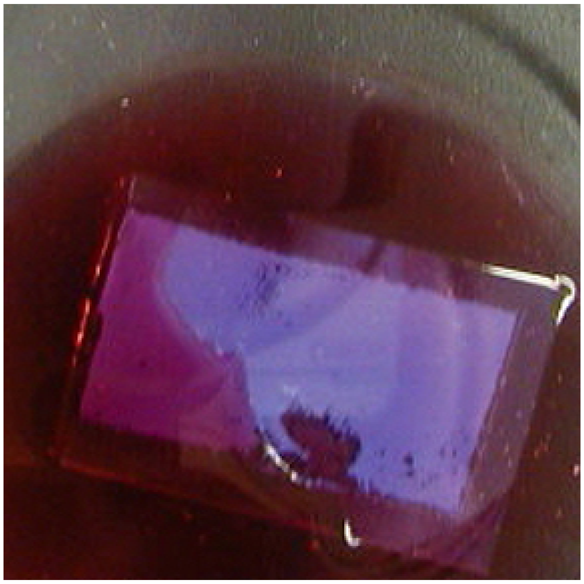

Image 04: face down in the filtered dye

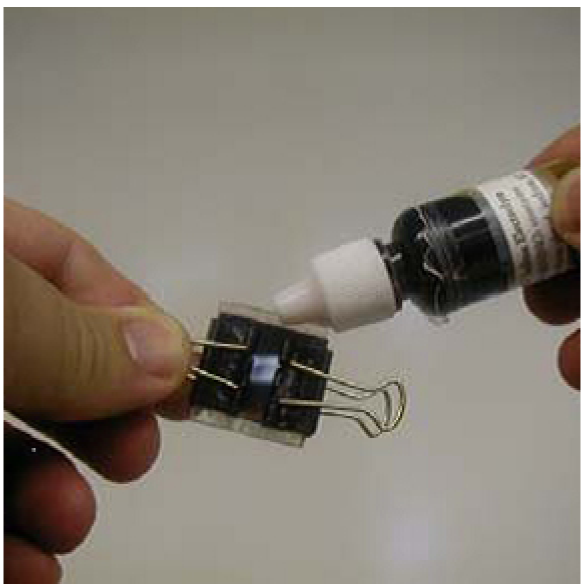

Image 05: binder clips hold both slides together

Nanofabrication of Solar Cells equipment kit for each group containing:

- small PV cell, at least 0.5v output, or several PV cells in series (found at most science supply companies and electronic stores)
- several sheets of colored transparency film in various colors, including yellow and blue (office supply stores) Small pieces should be cut beforehand just to cover the PV cells.
- 30 cm of thin electrical wire (use with alligator clips unless the meter leads have alligator clips on their ends)
- DC ammeter (reads amps)
- DC volt meter
- direct sunlight (desk lamp or flashlight could be substituted)

• magnifying glass
• aluminum foil
• protractor
• ice in sealed plastic bag
• goggles

Time	Activity Description	Subject
60 minutes	1 – Introduction and Reading Passage	Science Vocabulary Reading
90 minutes	2 – Lab Activity: Testing PV Cells	Science Math
45 minutes	3 - Assessments	Science Vocabulary
60 minutes	4 – Follow Up Lab: Activity – Energy Output from the Sun	Science Math Reading

Solar energy can be part of a mixture of renewable energy sources used to meet the need for electricity. Using photovoltaic cells (also called solar cells), solar energy can be used as direct current (DC) electricity or alternating current (AC) electricity or both. This electricity can be used at night by with a storage process, such as a battery. Batteries used for this purpose have a large storage capacity. Photovoltaic (PV) cells were developed in the 1950s as part of the space program.[8] They are made from silicon, a semiconductor. When light hits a PV cell, electrons move and travel along wires inside the PV cell, as electrons travel through the wiring in our homes. A PV cell changes sunlight into electricity by causing electrons to move toward the treated front surface of the cell. This creates an electron imbalance. When a connector like a wire joins the electron-reduced back and electron-increased front, a current of electricity flows between the negative front side and the positive back side. Photovoltaic systems are set up to maximize the Sun's light, and the system tracking angles can be changed for winter and summer, always facing the PV system south. Students are familiar with the PV cells used in most calculators. In fact, some students may wish to try some of the activities on a calculator PV cell for comparison. More possible future photovoltaic applications can be discussed with students.

Activity 1 Introduction and Reading Passage

Teachers should read the entire sequence of activities first, before starting the lab. Explain to the class the topic that will be covered in this unit of study. Teachers can include statements from the teacher background information section. Have students consider the following quote:

> "I think there is a world market for maybe five computers."
> Thomas Watson, chairman of IBM, 1943

Computers were initially costly and cumbersome. However, now almost everyone has access to or owns a computer. Photovoltaic systems were initially costly and cumbersome, but now? They are being used as a clean source of energy. Discuss with the class what they know about PV systems and their possibilities for use in and around the home and community. Each student will need a copy of the Reading Passage and the Student Data Sheets (includes reading comprehension questions, vocabulary words and Lab Activity). Instruct students to study the Reading Passage, "Introduction to Photovoltaic Systems,"[25] and complete the questions and vocabulary. This activity will help them learn about PV systems and some of their applications. Key vocabulary words in the Reading Passage will assist them in understanding the Lab Activity instructions. For students who wish to learn more of the detailed physics principles behind the operation of PV cells and other solid state devices, direct them to the appropriate resources. The suggested Resource Guide is http://www.rnp.org/RenewTech/tech_solar.html. Appropriate safety guidelines should also be reviewed.

Activity 2 Lab Activity Testing Photovoltaic Cells

1. Explain to the class that during this activity, students will test PV cell response to different wavelengths of light, shade, the angle and intensity of the Sun, and temperature. Emphasize to the class safety precautions when taking current and voltage readings using volt- and ammeters. Use either meter leads that have alligator clips on the ends, or attach insulated alligator clips to the wire ends that come into contact with the meter leads. Students should never touch any bare or exposed metal in a circuit that is generating electricity (i.e. meter leads, bare wire, etc.). Give students clear instructions on how to safely measure voltage and current using meters. The PV cell (or PV cells wired in series) needs at least 0.5 V output. The colored transparency sheets can be cut into pieces large enough to completely shade the PV cell.
2. Distribute copies of the Lab Activity to each student but have students work in groups (as determined by the teacher). Instruct students to review the Lab Activity before beginning and they will understand the goals and objectives. To enhance the class's scientific inquiry in this lab, instruct each student to develop statements for the following: hypothesis, predictions,

conclusions and finally significance/implications. Note that the hypothesis and predictions should be made before beginning the Lab Activity. Refer to the Resource Guide for more information http://www.rnp.org/RenewTech/tech_solar.html. Ask students to obtain a materials kit. Students should record their current and voltage readings in the tables provided in the Lab Activity. After students have completed their Data Tables, students should answer the data summary questions listed in the Lab Activity.

Expected Observations

Students should see the effects of more and less light and different wavelengths of light on the PV cell and of the cell's temperature. Voltage readings will be larger when more light is absorbed. Readings should be smaller when the PV cell is cold, though this temperature effect may be too minor to observe on a small scale. The PV cell should remain dry. The decreasing angles from the Sun (light source) result in lower readings.

Activity 3 Assessment

Distribute a copy of the Assessment Questions to each student. Instruct each student to work alone and answer the short answer and multiple-choice questions. Collect the handouts, grade and return them to the students.

Assessment Questions

1. What are three benefits of using solar power?

2. Does the future for both industrial and less developed countries hold a place for the use of photovoltaic systems? Discuss.

3. How could you increase the output of a PV cell during the day, when the angle of the sun's rays is constantly changing?

4. In what direction would you face a photovoltaic system being installed on your home? Explain

Multiple Choice Questions

---

1 The word photovoltaic comes from words meaning:

a) wind energy
b) brightness
c) light and electricity
d) picture which moves

2 A PV module is:

a) dozens of photovoltaic cells connected together
b) wired in series
c) wired in parallel
d) all answers a, b, c

3 Solar PV systems can be:

a) connected to the power grid
b) used to sell power to the grid
c) a stand alone source of electricity
d) all answers a, b, c

4 In the shade:

a) less light strikes the PV cells
b) less current is generated in PV cells
c) the PV cell is cooler
d) all answers a, b, c

5 Improving the efficiency of a PV cell can be done by:

a) adjusting the light facing angle all day
b) placing colored acetates on the cell
c) heating the cell
d) changing its direction to north

6 Solar photovoltaic cells were originally deployed for:

a) desert cooling
b) winter use
c) the space program
d) brick houses

7 Developing solar energy is important because it:

a) does not produce pollution
b) can be utilized in most regions of the U.S.
c) reduces our dependency on imported energy
d) all of the above

8 When planning your future home you will:

a) never consider photovoltaic systems
b) research the cost of a PV system as a supplement to the grid
c) work with local builders to find out if PV will be practical
d) b and c

9 The ammeter reads:

a) volts
b) amps
c) ohms
d) none of the answers

10 In a series connection:

a) the positive terminal is connected to the positive terminal
a) the negative terminal is connected to the negative terminal
b) the positive terminal is connected to the negative terminal
c) all of the above

SOLAR ENERGY TECHNOLOGY QUESTIONS

Name____ **Date**_________________

Reading/Resource Guide

1. Solar technologies convert the sun's light into ______________________ and ___________________________

2. What are the two major categories of solar energy technology?

____

____

3. Photovoltaic cells produce ____

4. There are two types of thermal solar systems. Describe them.

____

____

____

5. What are the fuel costs of solar systems? ____________________________________

6. Most of the costs of solar systems come from ________________________________

____

7. According to the article, what is the cost difference between photovoltaic systems and hot water systems? ____

8. Briefly describe the solar potential of the northwest. ________________________

____

9. How does the region compare to Germany regarding solar potential?

____

Why is this significant?____

10.Typical photovoltaic cells (PVs) are made from ______________________________

11.The cost per kWh of PV generated power ranges between __________________

12.Small PVs are often used in _________________________ areas because these areas are "off-grid" or too far from established transmission systems.

13.List three cost effective applications of PV generated power.

____

____

14.How much has the demand for Solar PV increased over the last 20 years?

____

15.Since 1982, solar cell prices have dropped from ___________________________to

____

16.Direct-use thermal systems are designed to heat water or air for individual buildings. List some specific uses. ____

____

17.What is the estimated cost of a direct thermal type of system? ______________

18.Briefly describe the environmental impacts of using either type of solar technology. ____

____

19.What is meant by "net metering"? ____

____

20.Net metering systems allow customers to install solar equipment without the need for ________________________________and _________________________________

____

21.Net metering is available in the following states: ___________________________

____

22.List four types of incentives available for the development of solar energy in the Northwest. ____

____

____

____

23.What is the increase in number of U.S. solar installations from 1998 to 2005?

____

24.Where can you get more information about solar energy?

____

____

Activity 4 Follow Up Lab

The Follow Up Lab can be conducted to expand the concept of energy from the Sun as it relates to heat energy. Students should understand that photons from the Sun create electricity with photovoltaic cells as well as heat with solar thermal collectors. Teachers should read and understand the Lab Activity and obtain the materials needed. Distribute a copy of the Follow Up Lab and instruct students to follow the steps.

ADDITIONAL ACTIVITY: Internet or Library Research

Students should research, compare and contrast the advantages of PV systems in the Caribbean, Mexico, and South America, where power grids are underdeveloped. Similarly, the increasing electricity costs and blackout potentials in the United States favor solar alternatives like the National Renewable Energy Laboratory built net zero-energy state-of-the-art research facility that generates more energy than it uses. [21and http://www.nrel.gov/sustainable_nrel/rsf.html]

Website(s)

http://volga.eng.yale.edu/pmwiki.php/Main/TeachingResources

Glossary Of Terms [23]

Anions: an ion consists of one or more atoms and carries a unit charge of electricity. Those that are negative ions (hydroxyl and acidic atoms or groups) are called anions (cf. cation).

Atom: the smallest unit of a chemical element, about a third of a nanometer in diameter. Atoms make up molecules and solid objects.

Atomic Force Microscopy / Microscope (AFM): atomic force microscopy is a technique for analyzing the surface of a rigid material all the way down to the level of the atom. AFM uses a mechanical probe to magnify surface features up to 100,000,000 times, and produces 3D images of the surface. The technique is derived from a related technology, called scanning tunneling microscopy (STM). The difference is that AFM does not require the sample to conduct electricity, whereas STM does. AFM also works in regular room temperatures, while STM requires special temperature and other conditions. AFM is being used to understand materials problems in many areas including data storage, telecommunications, biomedicine, chemistry, and aerospace. The atomic force microscope was invented in 1986. It uses various forces that occur when two objects are brought within nanometers of each other. An AFM can work either when the probe is in contact with a surface, causing a repulsive force, or when it is a few nanometers away, where the force is attractive.

Bar: a unit of pressure equal to one million (106) dynes, equivalent to 10 newtons, per square centimeter. This is approximately the pressure exerted by Earth's atmosphere at sea level.

Biomimetic: imitating, copying, or learning from nature.

Biomimetics: the design of systems, materials, and their functionality to mimic nature. Current examples include layering of materials to achieve the hardness of an abalone shell or understanding why spider silk is stronger than steel.

Bolometer: a device for measuring the energy of incident electromagnetic radiation.

Bottom up: building organic and inorganic structures atom-by-atom, or molecule-by-molecule.

Buckminsterfullerene: a sphere of sixty carbon atoms, also called a buckyball. Named after the architect Buckminster Fuller, who is famous for the geodesic dome that buckyballs resemble.

Buckyball: a popular name for Buckminsterfullerene.

Catalyst: a substance that increases the rate of a chemical reaction by reducing the activation energy, but which is left unchanged by the reaction. A catalyst works by providing a convenient surface for the reaction to occur. The reacting particles gather on the catalyst surface and either collides more frequently with each other or more of the collisions result in a reaction between particles because the catalyst can lower the activation energy for the reaction.

Cations: an ion consists of one or more atoms and carries a unit charge of electricity. Those that are positively electrified (hydrogen and the metals) are called cations (cf. anion).

Cell: a small structural unit, surrounded by a membrane, making up living things.

Chemical Vapor Deposition (CVD): a technique used to deposit coatings, where chemicals are first vaporized, and then applied using an inert carrier gas such as nitrogen.

Chirality: the characteristic of a structure (usually a molecule) that makes it impossible to superimpose it on its mirror image.

Colloid: a mixture in which one substance is divided into minute particles (called colloidal particles) and dispersed throughout a second substance. The mixture is also called a colloidal system, colloidal solution, or colloidal dispersion. Colloid science is the study of systems involving small particles of one substance suspended in another. Suspensions in liquids form the basis of a wide variety of systems of scientific and technological importance, including paints, ceramics, cosmetics, agricultural sprays, detergents, soils, biological cells, and many food preparations.

Complementary Metal-Oxide Semiconductor (CMOS): the semiconductor technology used in the transistors that are manufactured into most of today's computer microchips.

Composites: combinations of metals, ceramics, polymers, and biological materials that allow multi-functional behavior. One common practice is reinforcing polymers or ceramics with ceramic fibers to increase strength while retaining light weight and avoiding the brittleness of the monolithic ceramic. Materials used in the body often combine biological and structural functions (e.g., the encapsulation of drugs).

Dendrimer: a dendrimer is an artificially manufactured or synthesized molecule built up from branched units called monomers. Such processes involve working on the scale of nanometers. Technically, a dendrimer is a polymer, which is a large molecule comprised of many smaller ones linked together.

Diode: a diode is a specialized electronic component with two electrodes called the anode and the cathode. Most diodes are made with semiconductor materials such as silicon, germanium, or selenium. Diodes can be used as rectifiers, signal limiters, voltage regulators, switches, signal modulators, signal mixers, signal demodulators, and oscillators.

Dip Pen Nanolithography: a direct-write soft lithography technique that is used to create nanostructures on a substrate of interest by delivering collections of molecules via capillary transport from an AFM tip to a surface.

Dry Nanotechnology: derives from surface science and physical chemistry, focuses on fabrication of structures in carbon silicon, and other inorganic materials. Unlike the 'wet' technology, 'dry' techniques admit use of metals and semiconductors. The active conduction electrons of these materials make them too reactive to operate in a 'wet' environment, but these same electrons provide the physical properties that make 'dry' nanostructures promising as electronic, magnetic, and optical devices. Another objective is to develop 'dry' structures that possess some of the same attributes of the self-assembly that the wet ones exhibit.

Electro Scanning Microscope (ESM): used for the study of surface morphology and the determination of the thickness of MBE grown films.

Ellipsometry: a technique used to optically characterize material types such as semiconductors, dielectrics, metals, organic polymers and plastics in thin films, thin films stacks and in nanostructures. Ellipsometry does not contact or damage samples, and is an ideal and precise measurement technique for determining optical and, hence, physical and chemical properties of materials at the nanoscale. It is most commonly used to accurately measure film thickness and optical properties.

ESM: Electro Scanning Microscope

Fullerene: a Fullerene is a pure carbon molecule composed of at least 60 atoms of carbon. They are cage-like structures of carbon atoms; the most abundant form produced is Buckminster-fullerene (C_{60}), with sixty carbon atoms arranged in a spherical structure. Because a Fullerene takes a shape similar to a soccer ball or a geodesic dome, it is sometimes referred to as a buckyball after the inventor of the geodesic dome, Buckminster Fuller, for whom the Fullerene is more formally named.

HRTEM: High Resolution Transmission Electron Microscopy

Hydrocarbon: an organic compound that contains only carbon and hydrogen; classified, according to the arrangement of the atoms and the chemical properties of the compounds, as alicyclic, aliphatic, and aromatic; derived mostly from crude petroleum and also from coal tar and plant sources.

Ion: an atom or group of atoms in which the number of electrons is different from the number of protons. If the number of electrons is less than the number of protons, the particle is a positive ion, also called a cation. If the number of electrons is greater than the number of protons, the particle is a negative ion, also called an anion.

Langmuir-Blodgett: the name of a nanofabrication technique used to create ultrathin films (monolayers and isolated molecular layers), the end result of which is called a Langmuir-Blodgett film.

LCD (Liquid Crystal Display): technology used for displays in notebook and other smaller computers. LCDs allow displays to be much thinner than cathode ray tube technology. LCDs consume much less power because they work on the principle of blocking light rather than emitting it.

LED (Light Emitting Diode): a semiconductor device that emits visible light when an electrical current passes through it. The light is not particularly bright, but in most LEDs it is monochromatic, occurring at a single wavelength. The output from an LED can range from red (at a wavelength of ~700 nm) to blue-violet (~400 nm).

Ligand: an ion, a molecule, or a molecular group that binds to another chemical entity to form a larger complex.

Lithium Ion (Li-Ion) battery: a rechargeable battery with twice the energy capacity of a nickel-cadmium battery and greater stability and safety.

Macromolecule: a complex large molecule formed from simpler molecules, usually with a diameter ranging from about 100-10,000 angstroms (10^{-5} to 10^{-3} mm).

Matrix: substance within which something else originates, develops, or is contained.

Mechatronics: the study of the melding of AI and electromechanical machines to make machines that are greater than the sum of their parts.

MEMS: MicroElectroMechanical Systems

Microencapsulation: individually encapsulated small particles.

Microfluidics: the science of designing, manufacturing, and formulating devices and processes that deal with volumes of fluid on the order of nanoliters (symbolized nl and representing units of 10-9 liter) or picoliters (symbolized pl and representing units of 10-12 liter).

Molecular Assembler: also known as an assembler, a molecular assembler is a molecular machine that can build a molecular structure from its component building blocks.

Molecular Beam Epitaxy (MBE): process used to make compound (multi-layer) semiconductors. Consists of depositing alternating layers of materials, layer by layer, one type after another (such as the semiconductors gallium arsenide and aluminum gallium arsenide).

Moore's Law: the observation made in 1965 by Gordon Moore, co-founder of Intel that the number of transistors per square inch on integrated circuits had doubled every 18 months since the integrated circuit was invented. Moore predicted that this trend would continue for the foreseeable future MRI: Magnetic Resonance Imaging

MWNT: Multi Walled Nanotubes

Nano: a prefix meaning 10^{-9} or one billionth (1/1,000,000,000).

Nanoarray: an ultra-sensitive, ultra-miniaturized array for biomolecular analysis.

Nanobiotechnology: applies the tools and processes of nano/microfabrication to build devices for studying biosystems.

Nano-bubble: an ultra-fine gas bubble of diameter less than 1 Mm (1 Mm=1/1,000,000 m). It usually occurs temporarily in the process of shrinking a micro-bubble, but disappears soon because of its physical liability (constant change). Recently scientists have succeeded in producing stabilized nano-bubbles by collapsing micro-bubbles instantaneously in water containing electrolyte ions.

Nanocomposites: polymer/inorganic nanocomposites are composed of two or more physically distinct components with one or more average dimensions smaller than 100nm. From the structural point of view, the role of inorganic filler, usually as particles or fibers, is to provide intrinsic strength and stiffness while the polymer matrix can adhere to and bind the inorganic component so that forces applied to the composite are transmitted evenly to the filler.

Nanocomputer: a computer made from components (mechanical, electronic, or otherwise) built at the nanometer scale.

Nanocrystal: molecular-sized solids formed with a repeating, 3D pattern of atoms or molecules with an equal distance between each part. Nanocrystals are aggregates of anywhere from a few hundred to tens of thousands of atoms that combine into a crystalline form of matter known as a cluster. Typically around 10 nm in diameter, nanocrystals are larger than molecules but smaller than bulk solids and therefore frequently exhibit physical and chemical properties somewhere in-between. Nanocrystals are believed to have potential in optical electronics because of their ability to change the wavelength of light.

NanoElectroMechanical Systems (NEMS): a generic term to describe nanoscale electrical/mechanical devices. Nanoscale MEMS.

Nanoelectronics: electronics on a nanometer scale, whether made by current techniques or nanotechnology; includes both molecular electronics and nanoscale devices resembling today's semiconductor devices.

Nanofabrication: design and manufacture of devices with dimensions measured in nanometers.

Nanofibers: hollow and solid carbon fibers with lengths on the order of a few microns and widths varying from tens of nanometers to around 200 nm.

Nanofluidics: controlling nanoscale amounts of fluids.

Nanohorns: one of the SWNT (single walled carbon nanotube) types, with an irregular horn-like shape.

Nanoimprinting: see soft lithography.

Nanolithography: nanolithography is the art and science of etching, writing, or printing at the microscopic level, where the dimensions of characters are on the order of nanometers. This includes various methods of modifying semiconductor chips at the atomic level for the purpose of fabricating integrated circuits (ICs). Instruments used in nanolithography include the scanning tunneling microscope (STM) and the atomic force microscope (AFM). Both allow surface viewing in fine detail without necessarily modifying it. Either the STM or the AFM can be used to etch, write, or print on a surface in single-atom dimensions.

Nanomanipulation: The process of manipulating items at an atomic or molecular scale in order to produce precise structures.

Nanometer: one billionth (1/1,000,000,000) of a meter, 10^{-9} m, or a millionth of a millimeter.

Nano-optics: interaction of light and matter on the nanoscale.

Nanopores: nanoscopic pores found in purpose-built filters, sensors, or diffraction gratings.

Nanoscale: having dimensions measured in nanometers between 0.1-100 nm.

Nanoscience: the science of the controlling of matter on an atomic and molecular scale.

Nanosecond: one billionth of a second.

Nanoshells: nanoscale metal spheres that can absorb or scatter light at virtually any wavelength.

Nanosolids: solids that have dimensions measured in nanometers.

Nanospring: a nanowire wrapped into a helix.

Nanotechnology: the science of manipulating materials on an atomic or molecular scale especially to build microscopic devices, such as robots, where dimensions and tolerances are in the range of 0.1 nm to 100 nm.

Nanotube: a microscopic tube with a diameter measured in nanometers where dimensions and tolerances in the range of 0.1 nm to 100 nm, and particularly one of pure carbon.

Nanowires: one-dimensional structures, with unique electrical and optical properties, that are used as building blocks in nanoscale devices.

Photonics: electronics using light (photons) instead of electrons to manage data.

Scanning Electron Microscopy (SEM): utilized in medical science and biology and in such diverse fields as materials development, metallic materials, ceramics, and semiconductors. SEM involves the manipulation of an electron beam that is scanned across the surface of specially prepared specimens to obtain a greatly enlarged, high-resolution image of the specimen's exposed structure. Specimens are scanned with a very fine probe ('tip') and the strength of interaction between the tip and surface us monitored. The specimen can be observed whole for assessing external structure or freeze-fracture techniques can be used to image internal structures.

Scanning Force Microscope (SFM): a SFM works by detecting the vertical position of a probe while horizontally scanning the probe or the sample relative to the other. The probe is in physical contact with the sample and its vertical position is detected by detecting the position of a reflected laser beam with a photo diode that consists of two or four segments.

Scanning Near Field Optical Microscopy (SNOM): the operational principle behind near-field optical imaging involves illuminating a specimen through a sub-wavelength sized aperture whilst keeping the specimen within the near-field regime of the source. Broadly speaking, if the aperture-specimen separation is kept roughly less than half the diameter of the aperture, the source does not have the opportunity to diffract before it interacts with the sample and the resolution of the system is determined by the aperture diameter as oppose to the wavelength of light used. An image is built up by raster-scanning the aperture across the sample and recording the optical response of the specimen through a conventional far-field microscope objective. (As opposed to conventional optical microscopy or far-field optical microscopy).

Scanning Tunneling Microscope (STM): a device that obtains images of the atoms on the surfaces of materials - important for understanding the topographical and electrical properties of materials and the behavior of microelectronic devices. The STM is not an optical microscope; instead it works by detecting electrical forces with a probe that tapers down to a point only a single atom across. The probe in the STM sweeps across the surface of which an image is to be obtained. The electron shells, or clouds, surrounding the atoms on the surface produce irregularities that are detected by the probe and mapped by a computer into an image. Because of the quantum mechanical effect called 'tunneling' electrons can hop between the tip and the surface. The resolution of the image is in the order of 1 nm or less.

SEM: Scanning Electron Microscope

Semiconductor: a substance, usually a solid chemical element or compound that can conduct electricity under some conditions but not others, making it a good medium for the control of electrical current. Its conductance varies depending on the current or voltage applied to a control electrode, or on the intensity of irradiation by infrared (IR), visible light, ultraviolet (UV), or X rays.

SFM: Scanning Force Microscope

SIMS: Secondary Ion Mass Spectrometry

Soft lithography: a term for a collection of techniques (nanocontact printing, nanoimprinting, etc.) that are simple in concept and based around nanostructured forms, or molds.

Spintronics: electronics that exploits the spin of an electron in some way, rather than just its charge.

Sintered: to cause to become a coherent mass by heating without melting.

SNOM: Scanning Near Field Optical Microscopy

SPM: Scanning Probe Microscope

STM: Scanning Tunneling Microscope

Substrate: in nanotechnology the base material from which applications are built up.

SWNT: Single Walled Nanotubes

TEM: Tunneling Electron Microscope

Top down: refers to making nanoscale structures by machining and etching techniques.

Wet Nanotechnology: the study of biological systems that exist primarily in a water environment. The functional nanometer-scale structures of interest here are genetic material, membranes, enzymes and other cellular components. The success of this nanotechnology is amply demonstrated by the existence of living organisms whose form, function, and evolution are governed by the interactions of nanometer-scale structures.

XPS: X-ray Photoelectron Spectroscopy

Student Resources

Biomass energy [http://www.nrel.gov/learning/sr_biomass.html]

· Biofuels [http://www.nrel.gov/learning/sr_biofuels.html]

· Biopower [http://www.nrel.gov/learning/sr_biopower.html]

· Bioproducts [http://www.nrel.gov/learning/sr_bioproducts.html]

Geothermal energy [http://www.nrel.gov/learning/sr_geothermal.html]

· Geothermal direct use [http://www.nrel.gov/learning/sr_geo_direct_use.html

· Geothermal electricity production [http://www.nrel.gov/learning/sr_geo_elec_production.html]

· Geothermal heat pumps [http://www.nrel.gov/learning/sr_geo_heat_pumps.html]

Hydrogen energy [http://www.nrel.gov/learning/sr_hydrogen.html]

Solar energy [http://www.nrel.gov/learning/sr_solar.html]

· Concentrating solar power systems [http://www.nrel.gov/learning/sr_csp.html]

· Passive solar heating [http://www.nrel.gov/learning/sr_passive_solar.html]

· Photovoltaic (solar cell) systems [http://www.nrel.gov/learning/sr_photovoltaics.html]

· Solar hot water [http://www.nrel.gov/learning/sr_solar_hot_water.html]

Wind energy [http://www.nrel.gov/learning/sr_wind.html]

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Appendix

Alignment with the NCTM standards requires that the mathematics curriculum should make mathematics more accessible and relevant to students. These developed concepts and skills should be integrated throughout all subject areas. The following standards are addressed within this curriculum unit:

Standard 8: Communication.

The communication standard states that students should be given the opportunity to:

1. Organize and consolidate their understanding of mathematics through communication.
2. Communicate their mathematical thinking coherently and clearly.
3. Analyze and evaluate their mathematical thinking and strategies to others.
4. Use the language of mathematics to express mathematical ideas.

Standard 9: Connections.

The connections standard states that:

1. Students should be given the opportunity to recognize and use connections among mathematical ideas.
2. Recognize and use mathematics in contexts outside mathematics.

State/District Standards	
Nanotechnology Idea	**Standard it can address**
The idea of "Nano" - being small.	Structure of atoms.
Nanomaterials have a high surface area (nanosensors for toxins).	Structure and properties of matter, personal and community health, understanding about science and technology.
Synthesis of nanomaterials and support chemistry (i.e. Titanium Dioxide).	Chemical reactions
Shape memory alloys and smart materials.	Motion and forces, abilities of technological design, understanding about science and technology.
Nanocrystalline solar cells	Conservation of energy and increase in disorder (entropy), interactions of energy and matter, natural resources.
Nanocoatings resistive to bacteria and pollution.	Personal and community health, population growth, environmental quality, natural and human induced hazards.
Nanomaterials such as MR (magneto-resistive) fluids in security	Science and technology in local, national, and global challenges.
Richard P. Feynman's talk, "There is plenty of room at the bottom." Feynman had a vision.	Science as a human endeavor, nature of scientific knowledge, historical perspective.
Nanocosmetics and nanoclothing	Science as a human endeavor, science and technology in local, national, and global challenges.
Nanotechnology and Science Ethics	Science and technology in local, national, and global challenges, science as a human endeavor, historical perspective, natural and human-induced hazards, population growth, personal and community health.