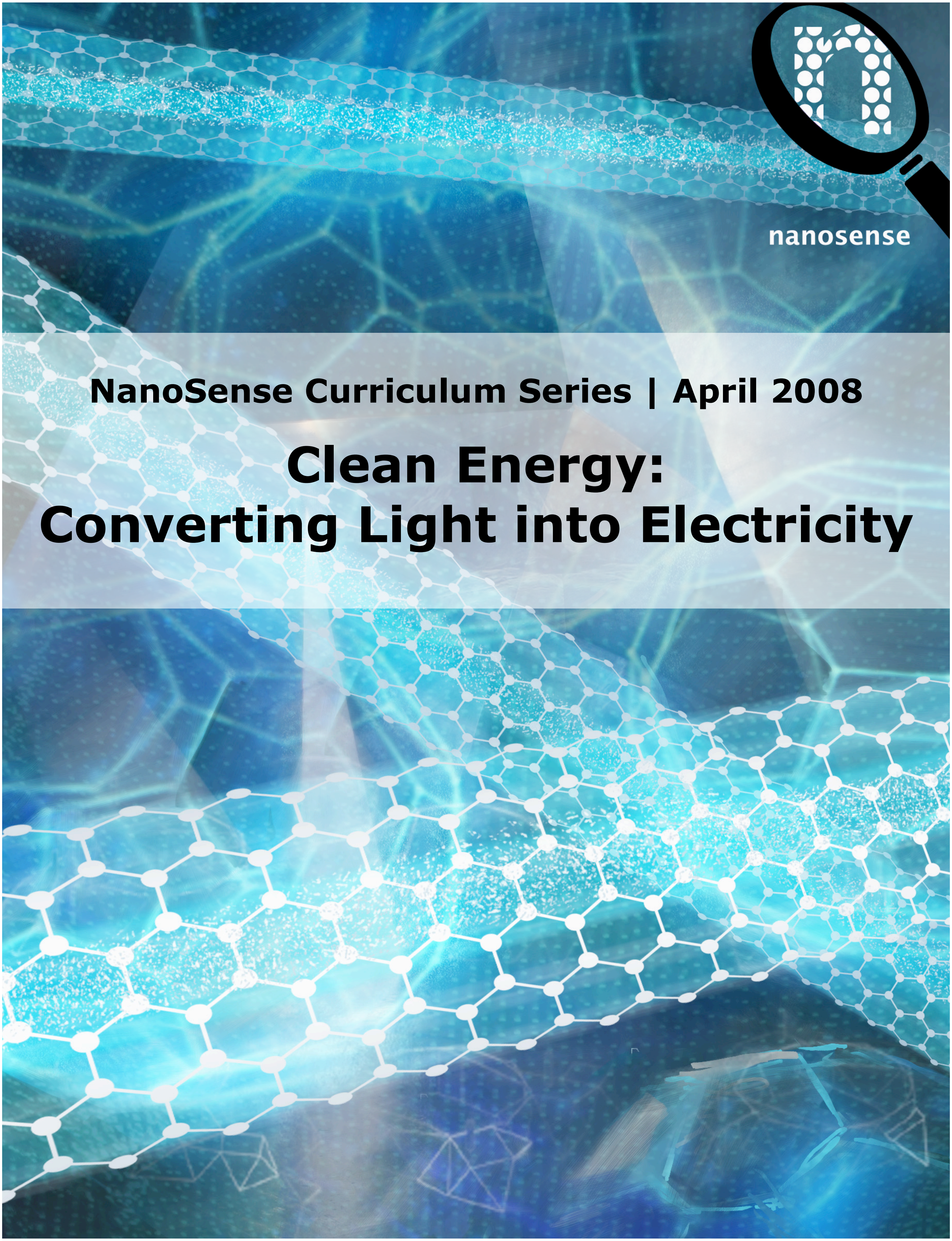

nanosense

NanoSense Curriculum Series | April 2008

Clean Energy: Converting Light into Electricity

NanoSense Curriculum Series

About the NanoSense Project

The goal of the NanoSense project is to help high school students understand science concepts that account for nanoscale phenomena. Working closely with partner teachers and scientists, the NanoSense team has created, classroom tested, and disseminated several units to help students understand underlying principles, applications, and implications of nanoscale science.

License Information

Attribution Information

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Electronic Versions of Materials

Electronic versions of all PowerPoint slides and other materials in this unit are available for download from the NanoSense Web Site at http://nanosense.org

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For Anyone Planning to Teach Nanoscience…
Read This First!

Nanoscience Defined

Nanoscience is the name given to the wide range of interdisciplinary science that is exploring the special phenomena that occur when objects are of a size between 1 and 100 nanometers (10^{-9} m) in at least one dimension. This work is on the cutting edge of scientific research and is expanding the limits of our collective scientific knowledge.

Nanoscience is "Science-in-the-Making"

Introducing students to nanoscience is an exciting opportunity to help them experience science in the making and deepen their understanding of the nature of science. Teaching nanoscience provides opportunities for teachers to:

- Model the process scientists use when confronted with new phenomena
- Address the use of models and concepts as scientific tools for describing and predicting chemical behavior
- Involve students in exploring the nature of knowing: how we know what we know, the process of generating scientific explanations, and its inherent limitations
- Engage and value our student knowledge beyond the area of chemistry, creating interdisciplinary connections

One of the keys to helping students experience science in action as an empowering and energizing experience and not an exercise in frustration is to take what may seem like challenges of teaching nanoscience and turn them into constructive opportunities to model the scientific process. We can also create an active student-teacher learning community to model the important process of working collaboratively in an emerging area of science.

This document outlines some of the challenges you may face as a teacher of nanoscience and describes strategies for turning these challenges into opportunities to help students learn about and experience science in action. The final page is a summary chart for quick reference.

Challenges & Opportunities

1. You will not be able to know all the answers to student (and possibly your own) questions ahead of time …

Nanoscience is new to all of us as science teachers. We can (and definitely should) prepare ahead of time using the resources provided in this curriculum as well as any others we can find on our own. However, it would be an impossible task to expect any of us to become experts in a new area in such a short period of time or to anticipate and prepare for all of the questions that students will ask.

… This provides an opportunity to model the process scientists use when confronted with new phenomena.

Since there is no way for us to become all-knowing experts in this new area, our role is analogous to the "lead explorer" in a team working to understand a very new area of science. This means that it is okay (and necessary) to acknowledge that we don't have all the answers. We can then embrace this situation to help all of our students get involved in generating and researching their own questions. This is a very important part of the scientific process that needs to occur before anyone steps foot in a lab. Each time we teach nanoscience, we will know more, feel more comfortable with the process for investigating what we don't know, and find that there is always more to learn.

One strategy that we can use in the classroom is to create a dedicated space for collecting questions. This can be a space on the board, on butcher paper on the wall, a question "box" or even an online space if we are so inclined. When students have questions, or questions arise during class, we can add them to the list. Students can be invited to choose questions to research and share with the group, we can research some questions ourselves, and the class can even try to contact a nanoscientist to help us address some of the questions. This can help students learn that conducting a literature review to find out what is already known is an important part of the scientific process.

2. Traditional chemistry and physics concepts may not be applicable at the nanoscale level …

One way in which both students and teachers try to deal with phenomena we don't understand is to go back to basic principles and use them to try to figure out what is going on. This is a great strategy as long as we are using principles and concepts that are appropriate for the given situation.

However, an exciting but challenging aspect of nanoscience is that matter acts differently when the particles are nanosized. This means that many of the macro-level chemistry and physics concepts that we are used to using (and upon which our instincts are based) may not apply. For example, students often want to apply principles of classical physics to describe the motion of nanosized objects, but at this level, we know that quantum mechanical descriptions are needed. In other situations it may not even be clear if the macroscale-level explanations are or are not applicable. For example, scientists are still exploring whether the models used to describe friction at the macroscale are useful in predicting behavior at the nanoscale (Luan & Robbins, 2005).

Because students don't have an extensive set of conceptual frameworks to draw from to explain nanophenomena, there is a tendency to rely on the set of concepts and models that they do have. Therefore, there is a potential for students to incorrectly apply macroscale-level understandings at the nanoscale level and thus inadvertently develop misconceptions.

… This provides an opportunity to explicitly address the use of models and concepts as scientific tools for describing and predicting chemical behavior.

Very often, concepts and models use a set of assumptions to simplify their descriptions. Before applying any macroscale-level concept at the nanoscale level, we should have the students identify the assumptions it is based on and the situations that it aims to describe. For example, when students learn that quantum dots fluoresce different colors based on their size, they often want to explain this using their knowledge of atomic emission. However, the standard model of atomic emission is based on the assumption that the atoms are in a gaseous form and thus so far apart that we can think about their energy levels independently. Since quantum dots are very small crystalline solids, we have to use different models that think about the energy levels of the atoms together as a group.

By helping students to examine the assumptions a model makes and the conditions under which it can be applied, we not only help students avoid incorrect application of concepts, but also guide them to become aware of the advantages and limitations of conceptual models in science. In addition, as we encounter new concepts at the nanoscale level, we can model the way in which scientists are constantly confronted with new data and need to adjust (or discard) their previous understanding to accommodate the new information. Scientists are lifelong learners and guiding students as they experience this process can help them see that it is an integral and necessary part of doing science.

3. Some questions may go beyond the boundary of our current understanding as a scientific community…

Traditional chemistry curricula primarily deal with phenomena that we have studied for many years and are relatively well understood by the scientific community. Even when a student has a particularly deep or difficult question, if we dig enough we can usually find ways to explain an answer using existing concepts. This is not so with nanoscience! Many questions involving nanoscience do not yet have commonly agreed upon answers because scientists are still in the process of developing conceptual systems and theories to explain these phenomena. For example, we have not yet reached a consensus on the level of health risk associated with applying powders of nanoparticles to human skin or using nanotubes as carriers to deliver drugs to different parts of the human body.

… This provides an opportunity to involve students in exploring the nature of knowing: how we know what we know, the process of generating scientific explanations, and its inherent limitations.

While this may make students uncomfortable, not knowing a scientific answer to why something happens or how something works is a great opportunity to help them see science as a living and evolving field. Highlighting the uncertainties of scientific information can also be a great opportunity to engage students in a discussion of how scientific knowledge is generated. The ensuing discussion can be a chance to talk about science in action and the limitations on scientific research. Some examples that we can use to begin this discussion are: Why do we not fully understand this phenomenon? What (if any) tools limit our ability to investigate it? Is the phenomenon currently under study? Why or why not? Do different scientists have different explanations for the same phenomena? If so, how do they compare?

4. Nanoscience is a multidisciplinary field and draws on areas outside of chemistry, such as biology, physics, and computer science…

Because of its multidisciplinary nature, nanoscience can require us to draw on knowledge in potentially unfamiliar academic fields. One day we may be dealing with nanomembranes and drug delivery systems, and the next day we may be talking about nanocomputing and semiconductors. At least some of the many areas that intersect with nanoscience are bound to be outside our areas of training and expertise.

… This provides an opportunity to engage and value our student knowledge beyond the traditional areas of chemistry.

While we may not have taken a biology or physics class in many years, chances are that at least some of our students have. We can acknowledge students' interest and expertise in these areas and take advantage of their knowledge. For example, ask a student with a strong interest in biology to connect drug delivery mechanisms to their knowledge about cell regulatory processes. In this way, we share the responsibility for learning and emphasize the value of collaborative investigation. Furthermore, this helps engage students whose primary area of interest isn't chemistry and gives them a chance to contribute to the class discussion. It also helps all students begin to integrate their knowledge from the different scientific disciplines and presents wonderful opportunities for them to see the how the different disciplines interact to explain real world phenomena.

Final Words

Nanoscience provides an exciting and challenging opportunity to engage our students in cutting edge science and help them see the dynamic and evolving nature of scientific knowledge. By embracing these challenges and using them to engage students in meaningful discussions about science in the making and how we know what we know, we are helping our students not only in their study of nanoscience, but in developing a more sophisticated understanding of the scientific process.

References

Luan, B., & Robbins, M. (2005, June). The breakdown of continuum models for mechanical contacts. *Nature 435*, 929-932.

Table 1. Challenges of teaching nanoscience and strategies for turning these challenges into learning opportunities.

	The Challenge…	Provides the Opportunity to…
1	You will not be able to know all the answers to student (and possibly your own) questions ahead of time	Model the process scientists use when confronted with new phenomena: Identify and isolate questions to answer Work collectively to search for information using available resources (textbooks, scientific journals, online resources, scientist interviews) Incorporate new information and revise previous understanding as necessary Generate further questions for investigation
2	Traditional chemistry and physics concepts may not be applicable at the nanoscale level	Address the use of models and concepts as scientific tools for describing and predicting chemical behavior: Identify simplifying assumptions of the model and situations for intended use Discuss the advantages and limitations of using conceptual models in science Integrate new concepts with previous understandings
3	Some questions may go beyond the boundary of our current understanding as a scientific community	Involve students in exploring the nature of knowing: How we know what we know The limitations and uncertainties of scientific explanation How science generates new information How we use new information to change our understandings
4	Nanoscience is a multidisciplinary field and draws on areas outside of chemistry, such as biology and physics	Engage and value our student knowledge beyond the area of chemistry: Help students create new connections to their existing knowledge from other disciplines Highlight the relationship of different kinds of individual contributions to our collective knowledge about science Explore how different disciplines interact to explain real world phenomena

Clean Energy: Overview, Learning Goals & Standards

Type of Courses:	Chemistry, Physics
Grade Levels:	10-12
Topic Area:	Clean, renewable energy sources; world energy demands; Solar energy conversion
Key Words:	Nanoscience, nanotechnology, energy, solar, alternative energy, renewable energy, chemical energy
Time Frame:	3 class periods (assuming 50-minutes classes)

Overview

Energy production is one of the most pressing global issues that humanity must address over the next few decades. Clean alternative technologies must be developed to provide sufficient energy to meet growing global demand. These energy solutions must be sustainable both environmentally (e.g., be nonpolluting) and economically (e.g., be efficient and scalable). Nanoscience could enable revolutionary and important breakthroughs in energy generation and conversion. In this unit, traditional and newer "nano" solar technologies are introduced and discussed.

Enduring Understandings (EU)

What enduring understandings are desired? Students will understand:

1. Clean alternative energy technologies must be developed to provide sufficient energy to meet growing global demand, and must be sustainable both environmentally and economically.
2. Nanoscience could enable important breakthroughs in solar energy technology through low cost, novel energy conversion mechanisms.
3. Surface area to volume ratio is a function of particle size and shape. Increasing surface area normally increases the rate of reaction because there are more sites available for simultaneous reactions.
4. Energy is neither created nor destroyed—it can only be converted into different forms.

Essential Questions (EQ)

What essential questions will guide this unit and focus teaching and learning?

1. What are some clean and renewable energy sources?
2. What are the main energy production mechanisms?
3. What are current and projected global energy demands?
4. How do newer, nanotechnology-influenced solar cells work, and how do they differ from traditional solar cells?

Key Knowledge and Skills (KKS)

What key knowledge and skills will students acquire as a result of this unit? Students will be able to:

1. Describe the three main global energy issues (limited supply of hydrocarbon-based resources, projected increase in global energy consumption, current lack of clean/renewable energy technologies).
2. Explain what single-crystal solar cells are and how they function.
3. Explain what nano-influenced dye-sensitized solar cells are, how they work, and the critical role surface area to volume ratio plays in their functioning.
4. Compare the main advantages/disadvantages of single-crystal silicon solar cells and dye-sensitized solar cells.

Prerequisite Knowledge

This unit assumes that students are familiar with the following concepts or topics:

1. Atoms, molecules, ions
2. Bonding
3. Energy, energy levels
4. Current, circuit, electrolysis, electrical power

NSES Content Standards Addressed

K-12 Unifying Concepts and Process Standard

As a result of activities in grades, K-12, all students should develop understanding and abilities aligned with the following concepts and processes: (2 of the 5 categories apply)

- Evidence, models and explanation
- Form and function

Grades 9-12 Content Standard A: Science as Inquiry

Abilities Necessary to Do Scientific Inquiry

- **Formulate and revise scientific explanations and models using logic and evidence.** Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical. In the process of answering the questions, the students should engage in discussions and arguments that result in the revision of their explanations. These discussions should be based on scientific knowledge, the use of logic, and evidence from their investigation. (12ASI1.4.)
- **Formulate and analyze alternative explanations and models.** This aspect of the standard emphasizes the critical abilities of analyzing an argument by reviewing current scientific understanding, weighing the evidence, and examining the logic so as to decide which explanations and models are best. In other words, although there may be several plausible explanations, they do not all have equal

weight. Students should be able to use scientific criteria to find the preferred explanations. (12ASI1.5.)

- **Communicate and defend a scientific argument.** Students in school science programs should develop the abilities associated with accurate and effective communication. These include writing and following procedures, expressing concepts, reviewing information, summarizing data, using language appropriately, developing diagrams and charts, explaining statistical analysis, speaking clearly and logically, constructing a reasoned argument, and responding appropriately to critical comments. (12ASI1.6.)

Understandings about Scientific Inquiry

- **Scientific inquiry about system function**. Scientists usually inquire about how physical, living, or designed systems function. Conceptual principles and knowledge guide scientific inquiries. Historical and current scientific knowledge influence the design and interpretation of investigations and the evaluation of proposed explanations made by other scientists**.** (12ASI2.1)
- **Scientific explanations**. Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge. (12ASI2.5)

Grades 9-12 Content Standard B: Physical Science

Structure of Atoms

- **Structure of atoms.** 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. (12BPS1.1)

Structure and Properties of Matter

- **Atomic interaction.** 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. (12BPS2.1)

Chemical Reactions

- **Energy and chemical reactions.** 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. (12BPS3.2)
- **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. (12BPS3.3)

- **Catalysts accelerate chemical reactions.** Catalysts, such as metal surfaces, accelerate chemical reactions. Chemical reactions in living systems are catalyzed by protein molecules called enzymes. (12BPS3.5)

Conservation of Energy and the Increase in Disorder

- **Total energy in universe is constant.** The total energy of 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. (12BPS5.1)
- **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. (12BPS5.2)

Interactions of Energy and Matter

- **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.
- **Electron flow in materials** 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. (12BPS6.4)

Grades 9-12 Content Standard E: Science and Technology

Abilities of Technological Design

- **Identify a problem or design an opportunity.** Students should be able to identify new problems or needs and to change and improve current technological designs. (12EST1.1)

Understandings about Science and Technology

- **Science advances through new technologies.** Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research. (12EST2.2)
- **Creativity, knowledge, imagination.** Creativity, imagination, and a good knowledge base are all required in the work of science and engineering. (12EST2.3)
- **The pursuit of science and technology.** Science and technology are pursued for different purposes. Scientific inquiry is driven by the desire to understand the natural world, and technological design is driven by the need to meet human

needs and solve human problems. Technology, by its nature, has a more direct effect on society than science because its purpose is to solve human problems, help humans adapt, and fulfill human aspirations. Technological solutions may create new problems. Science, by its nature, answers questions that may or may not directly influence humans. Sometimes scientific advances challenge people's beliefs and practical explanations concerning various aspects of the world. (12EST2.4)

Grades 9-12 Content Standard F: Science in Personal and Social Perspectives

Natural Resources

- **Human populations use resources.** Human populations use resources in the environment in order to maintain and improve their existence. Natural resources have been and will continue to be used to maintain human populations. (12FSPSP3.1)
- **Limited earth resources.** The earth does not have infinite resources; increasing human consumption places severe stress on the natural processes that renew some resources, and it depletes those resources that cannot be renewed. (12FSPSP3.2)
- **Human use natural systems.** Humans use many natural systems as resources. Natural systems have the capacity to reuse waste, but that capacity is limited. Natural systems can change to an extent that exceeds the limits of organisms to adapt naturally or humans to adapt technologically. (12FSPSP3.3)

Environmental Quality

- **Many factors influence environmental quality.** Many factors influence environmental quality. Factors that students might investigate include population growth, resource use, population distribution, overconsumption, the capacity of technology to solve problems, poverty, the role of economic, political, and religious views, and different ways humans view the earth. (12FSPSP4.3)

Natural and Human-Induced Hazards

- **Assessment of potential danger and risk.** Natural and human-induced hazards present the need for humans to assess potential danger and risk. Many changes in the environment designed by humans bring benefits to society, as well as cause risks. Students should understand the costs and trade-offs of various hazards--ranging from those with minor risk to a few people to major catastrophes with major risk to many people. The scale of events and the accuracy with which scientists and engineers can (and cannot) predict events are important considerations. (12FSPSP5.4)

Science and Technology in Local, National, and Global Challenges

- **Individuals and society must decide on proposals of new research/technologies.** Individuals and society must decide on proposals involving new research and the introduction of new technologies into society. Decisions involve assessment of alternatives, risks, costs, and benefits and consideration of who benefits and who suffers, who pays and gains, and what the risks are and who bears them. Students should understand the appropriateness and value of basic questions—What can happen? What are the odds? How do scientists and engineers know what will happen?" (12FSPSP6.4)

Grades 9-12 Content Standard G: History and Nature of Science

Nature of Scientific Knowledge

- **All scientific knowledge is subject to change as new evidence becomes available.** Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. The core ideas of science such as the conservation of energy or the laws of motion have been subjected to a wide variety of confirmations and are therefore unlikely to change in the areas in which they have been tested. In areas where data or understanding are incomplete, such as the details of human evolution or questions surrounding global warming, new data may well lead to changes in current ideas or resolve current conflicts. In situations where information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest. (12GHNS2.3)

Historical Perspectives

- **Changes in science by small modifications of current knowledge.** Usually, changes in science occur as small modifications in extant knowledge. The daily work of science and engineering results in incremental advances in our understanding of the world and our ability to meet human needs and aspirations. Much can be learned about the internal workings of science and the nature of science from study of individual scientists, their daily work, and their efforts to advance scientific knowledge in their area of study. (12GHNS3.2)
- **Scientific knowledge evolves over time, building on earlier knowledge.** The historical perspective of scientific explanations demonstrates how scientific knowledge changes by evolving over time, almost always building on earlier knowledge. (12GHNS3.4)

Unit at a Glance

Overview

The Clean Energy Unit has been designed in a modular fashion to allow you maximum flexibility in adapting it to your student's needs. Lesson 1 provides an overview of the current state of world energy consumption and production, and highlights the need for alternative energy sources. Lesson 2 is a two-day lesson that focuses on energy production using solar technologies and includes a hands-on student lab activity on nanocrystalline solar cells. You can use lessons 1 and 2 in sequence, or use them individually. The student nanocrystalline activity is a one-period activity, but can be extended into a two-period lab activity if you choose.

Lesson	**Basic Sequence**
Lesson 1: Introduction and Initial Ideas	√
Lesson 2: Solar Energy and Nanoscience	√

The following page contains a suggested sequencing of activities for the unit, as well as a listing of the Enduring Understandings (EU's), Essential Questions (EQ's), and Key Knowledge and Skills (KKS).

Suggested Sequencing of Activities for Basic Unit

Lesson	Teaching Days	Main Activities and Materials	Learning Goals	Assessment	Homework
Lesson 1: Introduction and Initial Ideas	1 day:	Clean Energy - The Potential of Nanoscience for Energy Production and Use: PowerPoint and Discusson Initial Ideas: Teacher Notes	EU: 1 KKS: 1	Initial Ideas Worksheet	Read "Hybrid Cars, Solar Cells, and Nanoscience" Complete Student Reading Worksheet
Lesson 2: Solar Energy and Nanoscience	2 days: *Day 1*	Clean Solar Energy - The Impact of Nanoscale Science on Solar Energy Production: PowerPoint and Discussion Solar Cell Animation Activity	EU: 2, 3, 4 KKS: 2, 3, 4, 5	Reflection on Guiding Questions	Read Nanoscrystalline Solar Cell Lab Activity handout
	Day 2	Nanoscrystalline Solar Cell Lab Activity Reflection on Guiding Questions		Nanoscrystalline Solar Cell Lab Worksheet	

Enduring understandings (EUs):

1. Clean alternative energy technologies must be developed to provide sufficient energy to meet growing global demand, and must be sustainable both environmentally and economically.
2. Nanoscience could enable important breakthroughs in solar energy technology through low cost, novel energy conversion mechanisms.
3. Surface area to volume ratio is a function of particle size and shape. Increasing surface area normally increases the rate of reaction because there are more sites available for simultaneous reactions.
4. Energy is neither created nor destroyed—it can only be converted into different forms.

Essential questions (EQs):

1. What are some clean and renewable energy sources?
2. What are the main energy production mechanisms?
3. What are current and projected global energy demands?
4. How do newer, nanotechnology-influenced solar cells work, and how do they differ from traditional solar cells?

Key Knowledge and Skills (KKS):

1. Describe three primary global energy issues (limited supply of hydrocarbon-based resources, projected increase in global energy consumption, current lack of clean/renewable energy technologies).
2. Explain what single-crystal silicon solar cells are and how they function.
3. Explain what nano-influenced dye-sensitized solar cells are, how they work, and the critical role surface area to volume ratio plays in their functioning.
4. Compare the main advantages/disadvantages of single-crystal silicon solar cells and dye-sensitized solar cells.

Alignment of Unit Activities with Learning Goals

Learning Goals	Lesson 1	Lesson 2
Presentation	*Introduction*	*Solar Energy and Nanoscience*
Activity	*Student Reading*	*Nanocrystalline Lab Activity* *Solar Cell Animation Activity*
Assessment	*Reading Worksheet, Initial Ideas Worksheet*	*Reflection on Guiding Questions Worksheet*
Students will understand…		
EU 1. Clean alternative energy technologies must be developed to provide sufficient energy to meet growing global demand, and must be sustainable both environmentally and economically.	•	
EU 2. Nanoscience could enable important breakthroughs in solar energy technology through low cost, novel energy conversion mechanisms.	•	•
EU 3. Surface area to volume ratio is a function of particle size and shape. Increasing surface area normally increases the rate of reaction because there are more sites available for simultaneous reactions.		•
EU 4. Energy is neither created nor destroyed—it can only be converted into different forms.	•	•
Students will be able to…		
KKS1. Describe the three main global energy issues (limited supply of hydrocarbon-based resources, projected increase in global energy consumption, current lack of clean/renewable energy technologies).	•	
KKS2. Explain what single-crystal silicon solar cells are and how they function.		•
KKS3. Explain what nano-influenced dye-sensitized solar cells are, how they work, and the critical role surface area to volume ratio plays in their functioning		•
KKS4. Compare the main advantages/disadvantages of single-crystal silicon solar cells and dye-sensitized solar cells.	•	•

Alignment of Unit Activities with Curriculum Topics

Chemistry

Unit Topic	Chapter Topic	Subtopic	Clean Energy Lessons	Specific Materials
Redox Chemistry	Electrochemistry	Electrochemical cells	• Lesson 2 (L2): Solar Energy and Nanoscience	**Slides** • L2: (all) **Activity/Handout** • Solar Cell Animations • Nanocrystalline Solar Lab
Chemistry of our World	Carbon Compounds	Hydrocarbons	• Lesson 1 (L1): Intro to Clean Energy	**Slides** • L1: 1-11 **Activity/Handout** • Reading: Hybrid Cars, Solar Cells, and Nanoscience

Physics

Unit Topic	Chapter Topic	Subtopic	Clean Energy Lessons	Specific Materials
Mechanics	Forces	Energy conversion Measurement Conservation of energy	• Lesson 2 (L2): Solar Energy and Nanoscience	**Slides** • L2: 2, 8, 10, 12
Light and Optics	Light Rays	Circuits Electron flow/current	• Lesson 2 (L2): Solar Energy and Nanoscience	**Teacher Reading** • L2: Teacher Reading **Activity** • Solar Cell Animation
Electricity and Magnetism	Electromagnetic Waves	Photoelectric effect E=hf; energy levels	• Lesson 2 (L2): Solar Energy (depending on how in depth teacher wants to get)	**Teacher Reading** • L2: Teacher Reading

Environmental Science

Unit Topic	Chapter Topic	Subtopic	Clean Energy Lessons	Specific Materials
Energy	A Sustainable Energy Future	Solar Energy	**Clean Energy** • Lesson 1 (L1): Intro to Clean Energy • Lesson 2 (L2): Solar Energy and Nanoscience	**Slides** • L1: 1-18 • L2: 1-18 **Activity/Handout** • L1: ○ Clean Energy Initial Ideas ○ Reading: Hybrid Cars, Solar Cells, and Nanoscience ○ Solar Cell Animations ○ Student Worksheet • L2: Nanocrystalline Solar Cell Lab

Biology

Unit Topic	Chapter Topic	Subtopic	Clean Energy Lessons	Specific Materials
Ecology	Humans in the Biosphere	Renewable and Nonrenewable Resources	• Lesson 1 (L1): Intro to Clean Energy • Lesson 2 (L2): Solar Energy and Nanoscience	**Slides** • L1: 1-18 • L2: 1-18 **Activity/Handout** • L1: ○ Clean Energy Initial Ideas ○ Reading: Hybrid Cars, Solar Cells, and Nanoscience ○ Student Worksheet • L2 ○ Nanocrystalline Solar Cell Lab ○ Solar Cell Animations

Clean Energy Pretest/Posttest: Teacher Answer Sheet

20 points total

1. List two advantages that nano-based, dye-sensitized solar cells can provide to address global energy issues. (2 points each, total of 4 points)

Possible answers include:

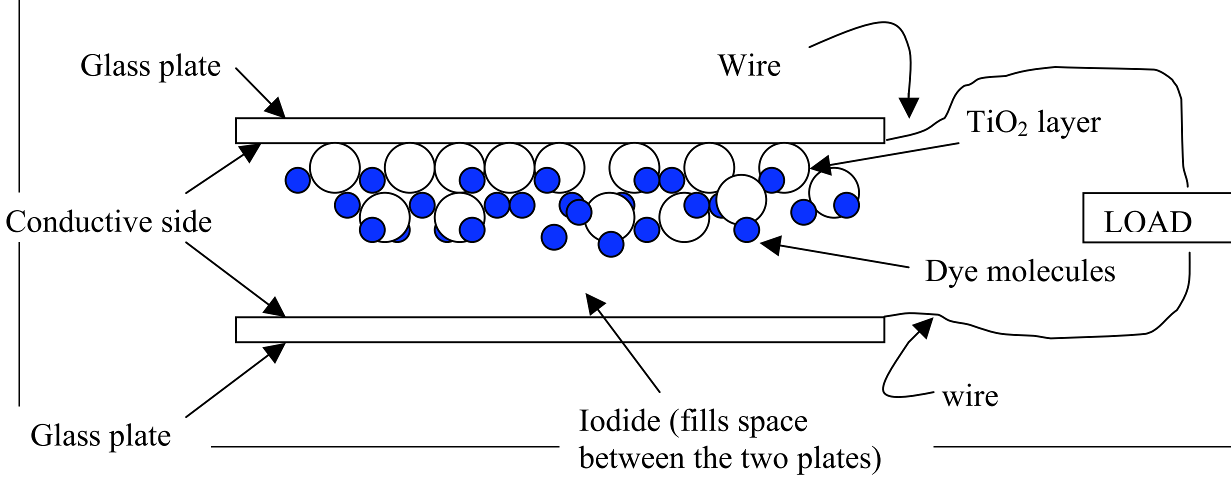
- Reduced pollution from the decrease in burning of fossil fuels (greenhouse gases, global warming, acid rain). Partial credit for associated issues (e.g. respiratory problems due to polluted air)
- Reduced dependency on fossil fuels (limited supply, bad for environment)
- Greater awareness of nanotechnology being used in positive ways to reduce our impact on the environment.
- Increased "economies of scale" – the more that nano-solar cells are used, the more they will be used in the future due to decreased manufacturing costs.
- Greater public acceptance and/or changing how people think about energy (conservation, "unlimited" supply, impact on environment)

2. Explain what you know about dye-sensitized solar cells, including an annotated diagram showing how they work. (6 points total)

Student should provide an explanation that hits on the following steps:

- light energy is absorbed
- electrons are released by the dye molecules (with positive "holes" left behind)
- electrons are infused into the TiO_2 and transported out of the cell
- the flow of electrons forms a current that drives a load
- electrons go back onto cell and are transported via the iodide solution back to the positive holes in the dye molecules.

Student should draw an annotated diagram similar in principle to the one below:



3. Why is it important that the titanium dioxide particles used in dye-sensitized solar cells be very small (aka "nano")? (6 points total)

The TiO_2 particles are very small – 10nm to 30 nm. These are coated with the dye molecules and stacked so that there are effectively many "layers" of dye molecules that can potentially absorb light. The TiO_2 is invisible to the light waves in the range that the dye molecules absorb the bulk of the light (400nm-900nm), which makes it so the light can pass right through them and can be available for the dye molecules. By using nano-sized TiO_2 particles, the **high surface to volume ratio** allows for a large surface area for the dye molecules to be spread across, thus increasing the probability of light being absorbed by the dye molecules.

4. What is the role of dye in a dye-sensitized solar cell? (4 points total)

The dye molecules absorb light energy and release electrons. The dye molecules sit on top of the TiO_2 particles. When an electron is released from the dye, it moves into the conduction band of the TiO_2.

Unit Overview

Student Materials

Contents

- (Optional) Clean Energy: Pretest
- (Optional) Clean Energy: Posttest

Name________________________________ Date_____________________ Period ______

Clean Energy: Pretest

1. List *three* global energy issues that you know about and provide two or three sentences describing each of them.

2. List what you think are *three* of the top energy sources currently used in the world.

3. Explain what you know about solar cells. Include a diagram with words that shows how you think a solar cell works.

4. Besides solar energy and the top energy sources you listed in question 2, provide two examples of other (alternative) energy sources that you know about with a short description of each.

Name________________________________ Date____________________ Period ______

Clean Energy: Posttest

1. List *three* global energy issues that you know about and provide two or three sentences describing each of them.

2. List what you think are *three* of the top energy sources currently used in the world.

3. Explain what you know about solar cells. Include a diagram with words that shows how you think a solar cell works.

4. Besides solar energy and the top energy sources you listed in question 2, provide two examples of other (alternative) energy sources that you know about with a short description of each.

Lesson 1: Introduction to Clean Energy

Teacher Materials

Contents

Introduction to Clean Energy: Teacher Lesson Plan

Orientation

This lesson is an introduction to the world's current dependency on fossil fuel-based energy sources and need for clean energy alternatives as we move forward. Our supply of fossil fuels is predicted to last through the middle of this century. This unit highlights the importance of planning now for how our energy needs will be met and how alternative energy sources are an important part of this equation.

- The Clean Energy—The Potential of Nanoscience for Energy Production and Use PowerPoint slide set provides a brief introduction to world energy issues and consumption rates. It includes short video clips from Nobel award-winning chemist Richard Smalley talking about world energy issues.
- The Clean Energy Initial Ideas Worksheet gives students the chance to work in small groups and generate ideas for discussion.
- The Student Reading on Hybrid Cars, Solar Cells, and Nanoscience provides some examples of energy technologies and how they relate to energy use.

Essential Questions (EQ)

What essential questions will guide this unit and focus teaching and learning?

(Numbers correspond to learning goals overview document)

1. What are some clean and renewable energy sources?
2. What are the main energy production mechanisms?
3. What are current and projected global energy demands?

Enduring Understandings (EU)

Students will understand:

(Numbers correspond to learning goals overview document)

1. Clean alternative energy technologies must be developed to provide sufficient energy to meet growing global demand, and must be sustainable both environmentally and economically.

Key Knowledge and Skills (KKS)

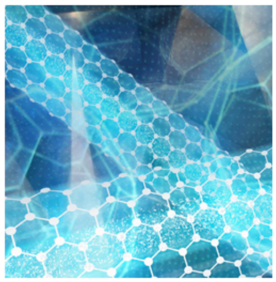
Students will be able to:

(Numbers correspond to learning goals overview document)

1. Describe the three main global energy issues (limited supply of hydrocarbon-based resources, projected increase in global energy consumption, current lack of clean/renewable energy technologies).

Introduction & Initial Ideas Timeline

Day	Activity	Time	Materials
Day 1 (50 min)	Show the Clean Energy–The Potential of Nanoscience for Energy Production and Use: PowerPoint slides, using the question slides and teacher's notes to start class discussion.	30 min	Clean Energy–The Potential of Nanoscience for Energy Production PowerPoint Slides & Teacher Notes Computer and projector
	Hand out the Initial Ideas Student Worksheet and have students work alone or in pairs to brainstorm answers to the driving questions. Let students know that at this point they are just brainstorming ideas and they are not expected to be able to fully answer the questions.	10 min	Copies of Clean Energy Initial Ideas: Student Worksheet Clean Energy Initial Ideas: Teacher Instructions
	Return to whole class discussion and have students share their ideas with the class to make a "master list" of initial ideas. The goal is not only to have students get their ideas out in the open, but also to have them practice evaluating how confident they are in their answers. This is also a good opportunity for you to identify any misconceptions that students may have to address throughout the unit.	10 min	
	Homework: Read the Hybrid Cars, Solar Cells, and Nanoscience: Student Reading and complete the worksheet.	*25 min*	Copies of Hybrid Cars, Solar Cells, and Nanoscience: Student Reading and Student Worksheet



Clean Energy

The potential of nanoscience for energy production and use

NanoSense
the basic sense behind nanoscience

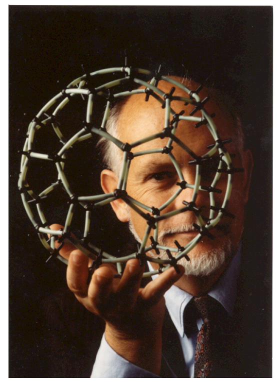
Top 10 Global Problems Over the Next 50 years

1.
2.
3.
4.
5.
6.
7.
8.
9.
10.

NanoSense 3

Richard Smalley (1943-2005)

- Nobel Prize winning chemist (1996)
- Discovered the "buckeyball" (C_{60})
- Leading nanoscience researcher
- "Be a scientist: save the world"



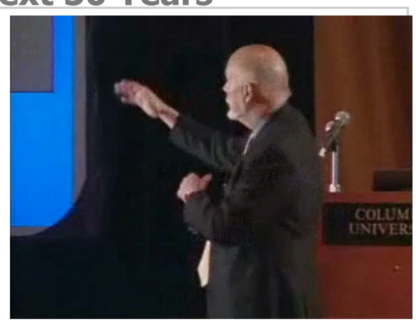
Dr. Smalley holding Buckeyball model

Source: http://physicsweb.org/objects/news/thumb/9/10/18/051018.jpg

NanoSense 4

Top 10 Global Problems for Next 50 Years

1. Energy
2. Water
3. Food
4. Environment
5. Poverty
6. Terrorism & War
7. Disease
8. Education
9. Democracy
10. Population



(click to start video)

2003 - 6.3 billion people
2050 - 10 billion people

Spurce: http://smalley.rice.edu

The Energy Problem

- **Energy is a major problem facing the world today**
- **We need to find the next sources of energy NOW**
- **We currently don't have the basic science and technology to solve this problem**

(click to start video)

Spurce: http://smalley.rice.edu

Dependency on Fossil Fuels

- **The World**
  - Is heavily dependent on fossil fuels: oil, coal, and gas
  - Consumes a large amount of on a daily basis
  - At projected consumption rates, will greatly diminish the earth's supply of oil and gas in the next 60-80 years

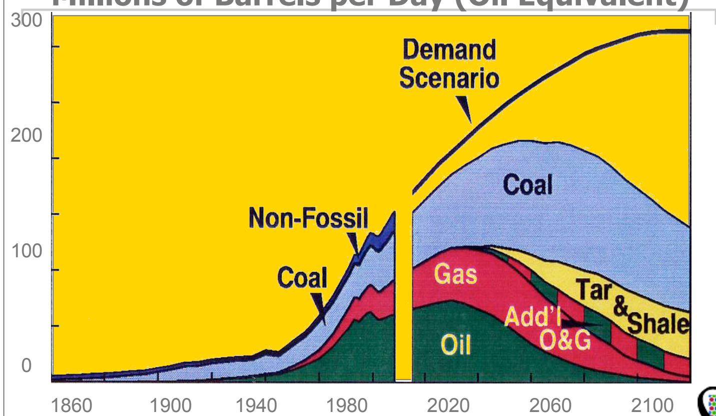
0000184125 barrels

> Global oil and gas consumption during this visit

NanoSense 7

World Energy

Millions of Barrels per Day (Oil Equivalent)

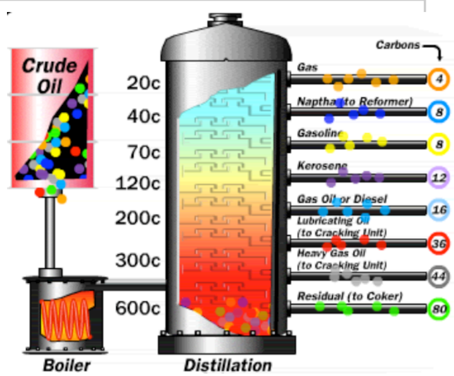


Source: John F. Bookout (President of Shell USA) ,"Two Centuries of Fossil Fuel Energy" International Geological Congress, Washington DC; July 10,1985. Episodes, vol 12, 257-262 (1989).

NanoSense 8

How is Oil Used?

- Oil is "distilled" or separated into many carbon-based products
- The products are used to power a range of devices, like cars and home heaters
- Used to make most plastics



Source: http://science.howstuffworks.com/oil-refining4.htm

NanoSense 9

How is Natural Gas (CH_4) Used?

- **For heating, cooking, and electric power generation**


Stove burner


Water heater

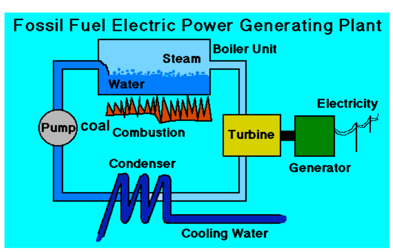

Furnace

Sources: http://static.howstuffworks.com/gif/water-heater-ch.jpg
http://www.naturalgas.org/overview/uses_residential.asp, http://www.ehponline.org/docs/2002/110-2/stove.jpg

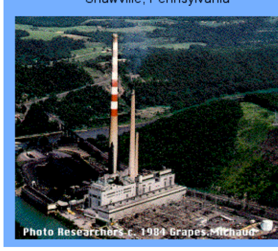
NanoSense 10

How is Coal Used?

- **To produce electricity**
  - Coal heats water to produce steam which drive turbines to produce electricity



Coal Burning Electric Power Plant
Shawville, Pennsylvania

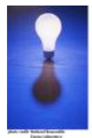


Source: http://www.elmhurst.edu/~chm/vchembook/193sources.html

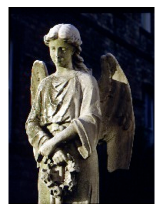
NanoSense 11

Pollution from Fossil Fuels: Coal Example

- **Running one standard 100 watt light bulb for a year uses 714 pounds of coal**
- **Pollutants from burning 714 pounds of coal include:**
  - 5 lbs Sulfur Dioxide (main cause of acid rain)
  - 5.1 lbs Nitrogen Oxides (causes smog, acid rain)
  - 1852 lbs Carbon Dioxide (greenhouse gas related to global warming)


Light Bulb


Coal


Statue damaged by acid rain

Sources: http://www.seismo.unr.edu/ftp/pub/louie/class/plate/coal.gif
http://science.howstuffworks.com/question481.htm
http://gallery.hd.org/_exhibits/natural-science/_more1999/_more05/acid-rain-stone-erosion-of-statue-2-AJHD.jpg
http://www.consumerenergycenter.org/homeandwork/homes/inside/lighting/images/incandescents.jpg

NanoSense 12

Addressing the Energy Problem

- **Some effort has gone into finding a solution**
  - Since 2001 over $10 billion spent by US on alternative energy R&D
  - Advanced Energy Initiative to help move US "beyond a petroleum-based economy"
  - Oil companies have been researching alternative energy solutions such as use of hydrogen (H_2)


Hydrogen-power Mini Cooper


Toyota Prius: highest selling gas-electric "hybrid" car

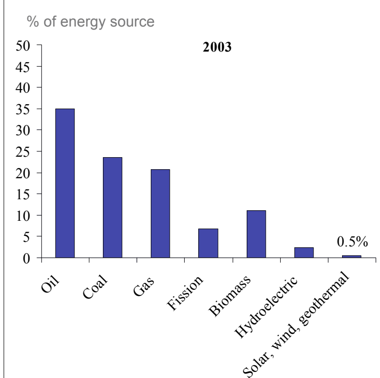
Sources: http://hybrids.autoblog.com/
http://www.ornl.gov/info/ornlreview/v38_1_05/images/a06_hydrogen_

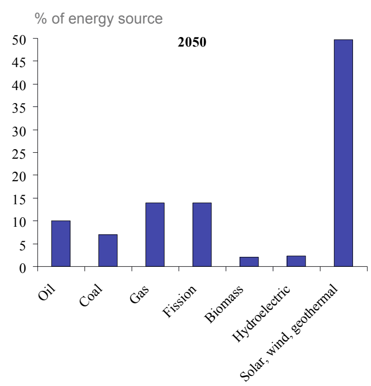
6

NanoSense 13

Energy Production Shift Over 50 Years

14 Terawatts Needed | 30-60 Terawatts Needed





Source: International Energy Agency

NanoSense 14

Solving the Energy Problem

- **One of the most important problems facing humanity today**
- **Many of the world's problems can be greatly improved if we solve the energy problem**
- **Clean, renewable energy is the key**
  - Considerable negative environmental issues arise otherwise

Sources: http://www.bbc.co.uk/norfolk/content/images/2005/12/30/melting_ice_caps_203_203x152.jpg
http://www.tashian.com/perl/jpeglook.pl?alpine-stream, http://www.tourist-info-vianden.lu/images/page043.jpg

NanoSense 15

Magnitude of the Energy Problem

(click to start video)

1 kilowatt = 1000 watts
1 terawatt = 10^{12} watts

A terawatt will run 13 million US homes for one day, or 36,000 US homes for one year

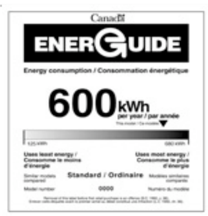
Projecting from usage today (15 terawatts), the world will need 30-50 terawatts of power by 2050

Spurce: http://smalley.rice.edu

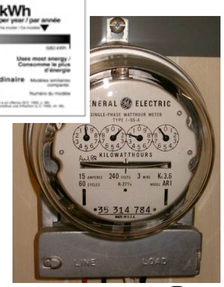
NanoSense 16

How Much is a Watt?

- **A watt = 1 joule of energy per second**
- **Energy is can be measured in *"kilowatt hours"* (kWh) - the amount of energy a 100 watt light bulb uses in 10 hours**
- **You can compare energy use by multiplying the kWh rating by running time (hours)**



Energy rating label



Electricity meter

Sources: http://oee.nrcan.gc.ca/Publications/infosource/Pub/appliances/images/10_clotheswash.jpg
http://www.driveev.com/jeepev/photos/pg21pics/kwhmeter/meter2.jpg

NanoSense 17

Energy Comparison of Home Appliances

- **Imagine you run a standard 100 watt bulb for 1 hour (0.1 kWh). With the amount of energy this takes, how long could you run:**

Running a 100 watt light bulb for 1 hour uses 0.1kWh of energy

A microwave oven?

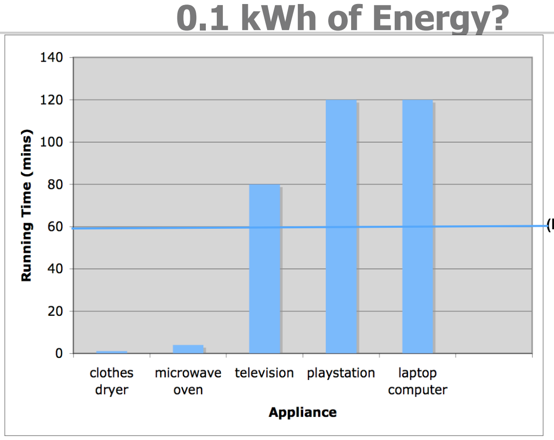
A television?

A laptop computer?

Sources: http://www.microwave-oven-system.com/uploads/m183dn_big.jpg,
http://www.computadora.com.ve/images/HP-NX9010-laptop-MainImage.jpg
http://www.exploreseville.com/images/basic-info/television.jpg, http://www.oakbridge.ca/graphics/lightbulb.jpg

NanoSense 18

How Long Can Each Appliance Run on 0.1 kWh of Energy?



(light bulb, for comparison)

Sources: http://michaelbluejay.com/electricity/howmuch.html
http://www.pica.army.mil/ voice2002/020809/dryer.jpg, http://www.laavenue.com/playstation.jpg

Clean Energy—The Potential of Nanoscience for Energy Production and Use: Teacher Notes

Overview

This series of interactive slides focuses on the world's current dependency on fossil fuels and the need to switch to alternative energy sources in the near future. There are several short video clips from a talk given by Richard Smalley that highlight our current energy demands as well as how many of the world's major problems can be positively impacted by abundant, "clean" energy.

Slide 1: Title Slide

Slide 2: Top 10 Global Problems Over the Next 50 Years

Ask your students: What are the top 10 global problems over the next 50 years? As a short 2-5 minute class activity, ask your students to brainstorm about what they think are the top 10 problems facing the world today. You can type the student responses into this slide in real time or list them on the board. We will return to this list on slide 4, in which students will watch a short video clip from one of Smalley's presentations where he lists the top 10 problems mentioned by most audiences.

Slide 3: Richard Smalley (1943-2005)

Before jumping into Smalley's list of top 10 global problems, this slide provides some background on Richard Smalley.

Richard Smalley was a chemist by training. In recent years, he became an advocate/spokesperson for clean energy through nanotechnology. Smalley won the Nobel Prize in Chemistry in 1996 for the discovery of a new allotrope of carbon that consists of 60 carbon atoms in the shape of a soccer ball. The molecule was named Buckminsterfullerene and given the nickname "buckyball." Smalley was very outspoken about the need for cheap, clean energy, which he described as the number one problem facing humanity in the 21st century. He felt very strongly that improving science education was key to solving this problem, and went to great lengths to encourage young students to consider careers in science. His heart-felt slogan was "Be a scientist, save the world."

See [1] and [2] for more on Richard Smalley. Also, there is a good, relatively short, autobiography of Dr. Smalley at [3].

Slide 4: Top 10 Global Problems for Next 50 years

This is the first of several short video clips of Smalley talking to audiences about energy and nanoscience. The transcript of this video clip is in the Appendix below.

Smalley gave this talk around the US over the past few years. During his presentations, he would poll his audience to identify what they thought were the top ten problems facing humanity today. He then discussed how most of the world problems could be solved or greatly improved by solving the "energy problem." This clip shows a compilation of audience responses to the top 10 global problems. You can compare your students' responses to the responses here.

Smalley's argument is that out of these top 10 problems facing the world, the energy problem is at the top. Solving the energy crises is also part of the solution for most of the other problems. During this video clip Smalley gives the example of water and how solving the water problem is directly related to solving the energy problem.

The ordering of items in the list is important: if you solve the things at the top of the list, the items lower on the list will be solved or greatly improved. When Richard Smalley did this with audiences, the items on the list and the ordering would change somewhat, but in general, most audiences agreed on the top seven problems.

Slide 5: The Energy Problem

This video clip on this slide is approximately 1 min 20 seconds, and introduces the energy problem. The transcript of this video clip is in the Appendix below.

Smalley claims that the number one problem facing humanity is the shortage of energy. We currently do not have the technological capacity to solve the energy production problem for this century; the problem that oil solved for the last century. There might not be one source, one primary energy source, that we will rely on: the solution might be a mix of sources, such as solar, wind, clean coal, nuclear, and hydrogen fuel.

Smalley makes reference to the unit "terawatt." You can get into measures of power at this point (or later), or just talk more generally about a "watt" and a "terawatt" as being measures of power. One watt is 1 joule/second; so power is a *rate*, a flow of energy, rather than a *quantity*.

Note that there is an *optional* set of slides (slides 16-19) at the end of this presentation that talk more specifically about power and consumption rates.

Slide 6: Dependency on Fossil Fuels

This slide highlights that the world currently consumes a large amount of oil daily. The counter is a real-time approximation of the amount of energy in the form oil and gas that the world is currently consuming. Students might be amazed/shocked by the sheer volume. Note that at this rate the world's oil supply will be depleted in the next 60-80 years. This counter was taken from a page on a Chevron website [4] that talks about the need for alternative forms of energy.

Slide 7: World Energy

This slide depicts the projected use (and depletion) of top global energy resources. The graph shows projections for energy consumption in the future based on current energy growth rates and the projected limits of currently known carbon-based sources. This graph is important because it shows the drop-off in available energy sources, such as oil, gas, and coal, over this century. This graph suggests that we need to be thinking ahead about renewable (and clean) energy sources since we can't rely much longer on many of the current sources of energy we are used to.

Some things you can do with your students:

- Highlight the oil, gas, and coal demand lines
- Explain what "Demand Scenario" means (projected future need)
- Point out that the yellow gap between the demand scenario and the energy supply is what needs to be filled in by some other source(s) of energy (e.g. solar, hydrogen fuel, wind, hydroelectric)

Note that this big shift will happen during your students lifetimes. Some questions to ask them:

- What are the implications for them?
- What do they think about this?
- What do THEY think the implications will be?
- What do they think might help solve this issue?

Slide 8: How is Oil Used?

This slide roughly shows the distillation process of crude oil. The point of this slide is to highlight that generic crude oil—the "barrels" that are traded in the energy market—are broken down into a variety of energy sources, not just gasoline for you car (although this is one of the most popular products extracted from crude oil.) In this example, the distillation process breaks large hydrocarbons into smaller pieces. Note that some products need to go though additional processes (e.g. heavy gas oil needs to go to the cracking unit) to be turned into useful energy sources. For a given barrel of oil, multiple processes are employed so as to extract as much useful energy products as possible out of the oil.

You can point out to your students the variety of products that come from the distillation process. Temperature and pressure are the main factors in differentiating/extracting different forms of energy. Also note the number of carbon atoms for each product. The oil refining process is very "chemical education" rich since it is involves various methods for the breakdown of hydrocarbons. For more information on how oil refining works, see [5], which has good explanations of the various processes and products along with good images and animations.

Slide 9: How is Natural Gas (CH_4) Used?

This slide highlights natural gas as another primary energy source used today. Natural gas, commonly referred to as gas, is a gaseous fossil fuel consisting primarily of the molecule methane. It is found in oil fields and natural gas fields, and in coal beds.

Some additional information (from [6]) on natural gas follows, in case you want to share this with your students.

Chemical Composition. The primary component of natural gas is methane (CH_4), the shortest and lightest hydrocarbon molecule. It also contains heavier gaseous hydrocarbons such as ethane (C_2H_6), propane (C_3H_8) and butane (C_4H_{10}), as well as other sulphur containing gases in varying amounts, (see also natural gas condensate).

Background and Power Generation. Natural gas is a major source for electricity generation through the use of gas turbines and steam turbines. Environmentally, natural gas burns cleaner than other fossil fuels, such as oil and coal, and produces fewer greenhouse gases. For an equivalent amount of heat, burning natural gas produces about 30% less carbon dioxide than burning petroleum and about 45% less than burning coal. Natural gas is expected to peak around the year 2030, 20 years after the peak of oil. It is also projected that the world's supply of natural gas will be depleted around the year 2085. Natural gas is tasteless and odorless, but before it is distributed, it is odorized by adding mercaptans or thiols to assist in leak detection.

Slide 10: How is Coal Used?

The important main takeaway for this slide is that coal is used heavily in the production of electricity for our homes and businesses. A coal burning electric power plant, in the simplest terms, converts chemical energy stored in coal into electrical energy. As you may guess, because coal is burned in the process of generating electricity, there is considerable pollution. In the diagram, coal is burned to boil water and produce steam. This steam is forced through turbines—devices that turn when steam passes over them—which spin generators that produce electricity.

More background (from [7]): A fossil fuel power plant is an energy conversion center that combusts fossil fuels to produce electricity, designed on a large scale for continuous operation. In a fossil fuel power plant, the chemical energy stored in fossil fuels—such as coal, fuel oil, or natural gas—is converted into thermal energy, mechanical energy, and finally, electrical energy. Electrical energy is for continuous use and distribution across a wide geographic area. Almost all large fossil fuel power plants are steam-electric power plants, except for gas turbines and utility-sized reciprocating engines that may run on natural gas or diesel. In the plant, pulverized coal is blown into the furnace and rapidly combusts, heating water that circulates through boiler tubes and drives a series of steam turbines interconnected to each other and to a generator on a common shaft.

A nice Flash animation on the operation of a fossil fuel power plant can be viewed/interacted with at [8].

Slide 11: Pollution from Fossil Fuels: Coal Example

This slide provides an example of how much energy you can get from coal to power a light bulb. Note the amount of pollutants produced just to run one light bulb for a year! There are plenty of opportunities to talk about chemistry here; below are some examples.

Smog. Classic smog results from large amounts of coal burning in an area and is caused by a mixture of smoke and sulphur dioxide. Sulfur dioxide (also sulfurous anhydride or sulfurous anhydride) has the chemical formula SO_2. The gas is irritating to the lungs and is frequently described as smelling of burning sulfur. It is produced by volcanoes and in various industrial processes. In particular, poor-quality coal and petroleum contain sulfur compounds and generate sulfur dioxide when burned. The gas reacts with water and atmospheric oxygen to form sulfuric acid (H_2SO_4) and acid rain. In power plants using sulfur containing coal or oil, the sulfur dioxide can be chemically bound by flue gas desulfurization (removing sulfur dioxide from the exhaust flue gases in power plants that burn coal.) Calcium oxide reacts with sulfur dioxide to form calcium sulfate (gypsum). Most of the gypsum sold in Europe comes from this source. $CaO + SO_3 \rightarrow CaSO_4$

Acid rain. Acid rain is defined as any type of precipitation with a pH that is unusually low. It can increase the acidity of soil and affect the chemical balance of lakes and streams. The process begins when sulfur dioxide and nitrogen oxides are emitted into the atmosphere. These molecules are absorbed by water droplets in clouds and undergo chemical transformations that cause the water to become acidic. The droplets then fall to earth as rain, snow, or sleet. Dissolved carbon dioxide dissociates to form weak carbonic acid, giving a pH of approximately 5.6 at typical atmospheric concentrations of CO_2. A pH of < 5.6 has sometimes been used as a definition of acid rain. However, natural sources of water in remote areas often have a pH between 4.5 and 5.6 with an average value of 5.0, so rain with a pH < 5 may be a more appropriate definition.

Slide 12: Addressing the Energy Problem

This slide makes the point that our government and some companies have been looking ahead towards a solution to the energy problem. However, we have a long way to go. For example, in order to distribute hydrogen to cars, the current gasoline fueling system would need to be replaced, or at least significantly supplemented with hydrogen fuel stations. Hydrogen stations are being built in various places around the world, but replacing the existing gasoline fuel station infrastructure would cost half a trillion dollars in the United States alone [9].

Interesting fact: The U.S. Department of Energy was set up to provide stable energy supply for the U.S. Their mission is to advance the national, economic, and energy security of the United States; to promote scientific and technological innovation in support of that mission; and to ensure the environmental cleanup of the national nuclear weapons complex. More information can be found at www.energy.gov.

Slide 13: Energy Production Shift Over 50 Years

We have already talked about oil, coal, and gas, which are considered fossil fuel sources of energy. The graph on the left shows that most of our current energy needs are met from fossil fuel sources. But the supply of fossil fuels is limited. We need to be thinking ahead, not just about sources of energy, but also about how clean and renewable they are.

This slide shows the shift of energy sources over 50 years. Note the shift away from oil, coal, and gas to more renewable sources such as nuclear (fission), biomass, hydroelectric, solar, wind, and geothermal. This shift is imperative as our supply of fossil fuels is diminishing. Below is a short description of each of the alternative fuel sources for discussion with your students.

Nuclear (fission). Nuclear fission, also known as atomic fission, is a process in which the nucleus of an atom splits into two or more smaller nuclei and (often) some other by-product particles. When the original nucleus splits into smaller pieces, energy is released, making nuclear fission useful as a power source. Some materials, called nuclear fuels, generate neutrons as part of the fission process and also undergo triggered fission when impacted by a free neutron. Nuclear fuels can be part of a self-sustaining chain reaction that releases energy at a controlled rate in a nuclear reactor or a very rapid uncontrolled rate in a nuclear weapon. The amount of free energy contained in nuclear fuel is millions of times the amount of energy contained in a similar mass of chemical fuel, such as gasoline, making nuclear fission a very tempting source of energy. There is a concern, however, that the waste products of nuclear fission are highly radioactive (damaging to all living organisms) and remain so for millennia, giving rise to a nuclear waste problem. Concerns over nuclear waste accumulation and the immense destructive potential of nuclear weapons give rise to intense ongoing political debate over nuclear power.

Biomass. Biomass is an environmentally friendly, organic non-fossil material. Biomass describes the mass of all biological organisms, dead or alive, excluding biological mass that has been transformed by geological processes into substances such as coal or petroleum. Typically, biomass refers to plant matter that can be processed into various industrial fuels, including biodiesel, methanol and ethanol. Biomass can come from plants including hemp, corn, and sugarcane.

Hydroelectric. Hydroelectricity is electricity obtained from hydropower. Most hydroelectric power comes from the potential energy of dammed water driving a water turbine and generator. Less common variations make use of water's kinetic energy or un-dammed sources such as tidal power.

Solar. The term solar power is used to describe a number of methods of harnessing energy from the light of the sun. Solar energy has been harnessed by traditional building methods for centuries. Interest in solar energy has grown as the environmental costs of using fossil fuels and nuclear power and the diminishing supply of fossil fuels are considered. It is already in widespread use where other power supplies are absent, such as in remote locations and in space. See [10] for an extensive discussion of various solar technologies.

Wind. Most modern wind power is generated in the form of electricity by converting the rotation of turbine blades into electrical current by means of an electrical generator. In windmills (a much older technology), wind energy is used to turn mechanical machinery to do physical work, like crushing grain or pumping water. Wind power is used in large-scale wind farms for national electrical grids, as well as in small individual turbines for providing electricity in isolated locations. Wind energy is abundant, inexhaustible, widely distributed, clean, and mitigates the greenhouse effect.

Geothermal. Geothermal literally means earth heat. Geothermal power is the use of heat energy from hot areas under the surface of the earth for electricity generation. In areas with high temperature ground water at shallow depths, wells are drilled into natural fractures in basement rock or into permeable sedimentary rocks. Hot water or steam flows up through the wells by pumping or through boiling (flashing) flow. Geothermal energy is often referred to as a form of renewable energy, but because the heat at any location can eventually be depleted, it technically may not be strictly renewable.

Slide 14: Solving the Energy Problem

Important to note that it is not just about producing enough energy, but also producing enough **clean** energy. If we don't come up with renewable, clean energy sources, we could exacerbate harmful environmental impacts (e.g., global warming).

Note: You can end the slide presentation here, unless you want to cover the 4 additional "magnitude of the energy problem" slides below. These final slides can be used if you are interested in quantifying and comparing energy consumption. They examine watts and terawatts, and compare the power consumption of various appliances.

Slide 15: Magnitude of the Energy Problem (Optional)

This video clip is about 1 minute long and talks about how much energy we will need to produce in the near future. The transcript of this video clip is in the Appendix below.

A possible student activity (e.g., a short homework activity followed by a few minutes of class discussion the following day) would be for each student to calculate his or her family's "energy footprint." Ask your students to look at their energy bill at home, figure out how much energy their family uses on a monthly or yearly basis, and report back on what they find. To frame the activity, you may want to bring in your electricity bill and talk about how to determine your energy footprint.

Slide 16: How Much is a Watt?

You can compare the power used by devices by comparing their power consumption in watts or kilowatts. The power used by a device can be determined looking at its power settings, usually listed on the device. The energy consumed by a device can be calculated by multiplying the power used by the device by the running of time the device. A kilowatt hour is the typical measure of energy use. A kilowatt (kW) is 1,000 watts, and a "kilowatt hour " refers to the use of a device or a set of devices that use 1,000 watts for an hour. Therefore, using a 100-watt light-bulb for 10 hours would equate to 1 kilowatt hour, as would the use of a 5,000 watt microwave oven for 12 minutes. A typical US household uses approximately 7,500 kilowatt hours of energy per day.

Number of joules in a kilowatt-hour: 3600seconds x 1000 watts. Joules aren't commonly used in daily life because they are so small that we'd have to deal with lots of zeros or scientific notation.

Slide 17: Energy Comparison of Home Appliances

This slide sets up the next slide that shows a comparison of energy used by different appliances. Have your students take some guesses at how long they think a microwave oven or a TV might run on the same amount of energy that a 100W bulb will use in an hour. The next slide presents an energy usage comparison between these devices.

Slide 18: How Long Can Each Appliance Run on 0.1 kWh of Energy?

This slide presents a bar chart comparison between the running time of typical household appliances based on the amount of energy need to power a 100-watt light bulb for 1 hour (0.1 kWh). Notice that bulbs use a surprising amount of energy to run. Notice also the dramatic difference between the dryer (electric) and the laptop. You can also point out that if you listed a cell phone on this graph, its bar would extend about 12 times higher than the laptop bar! That is, it would run 12 times longer (about 24 hours total) than a laptop given the amount of energy needed to power a 100-watt light bulb for 1 hour.

Appendix: Transcript of Video Clips of Richard Smalley

Transcript for Slide 4 Video: Top 10 Global Problems for Next 50 years

I have now given a summary of the sort of answers I've gotten. In fact these 10 problems were suggested by those 14 audiences. The top 7 were suggested by every one of them. The remaining 3 are a set of about 67 other problems that were suggested. And I've ordered them here in the order of the immediacy of the effect of energy on the problem.

It's interesting that what many people believe is the single most important problem, it isn't energy—water—bubbles right up to the top of the list. And let me just pick on that as an example. Water is a very brutal problem. Either you've got it or you don't. If you don't have it, you can't pretend that you've got it. You've got to go get that water molecule. Either from somebody else who's got the water or some place far away. Luckily on our planet there is plenty of water. In fact we probably have more water than anything else. But it has salt in it, and it's often thousands of miles away from where we need it. And we need it in vast amounts—hundreds of millions of gallons a day.

Well, we can take the salt out of the water. There's no doubt some neat little nano thing will do it in 100% thermodynamic efficiency or close to it. Or you can just boil the water. But you can do it if you have the energy. Of course you need a lot of low-cost energy because you need hundreds of millions of gallons a day. And you've got to put it in pipe and pump it off to where you need it, which might be thousands of miles. But we can make pipes, and we know how to pump them. We know how to do that whole thing, but it costs energy to make them, it costs energy to maintain them, and energy to pump the water from here to there.

But we could do it. If we have the energy, we can solve the water problem! I mean solve it! For 10 million people everywhere on the planet, even places that don't rain. But if you haven't got the energy, you can't solve the problem. There's just no way.

Transcript for Slide 5 Video: The Energy Problem

So let's go back to this one issue of can we all agree that what the most important problem for humanity is. That would be quite an accomplishment.

So here's the argument. And the way I've gotten this to this point is I have asked audiences—not quite as grand as this—but on the spur of the moment, not knowing I'm going to talk about energy, I've put up basically this PowerPoint slide with the numbers 1 through 10 with blanks after them, and I've asked the audience, "What do you think deserves to be on this list?" So the question is cast with the world staring you in the face.

I want to know problems for the world, for humanity world wide, not just locally in New York City or in Texas. And I'm casting it at mid-century, so we're far enough away from the idiosyncrasies of our current political and economic realities, but not so far away that it's irrelevant, particularly for the energy issue, if you turn up with that for the answer since you need so many years to get into it to build the technology.

Transcript for Slide 15 Video: Magnitude of the Energy Problem

We just can't… if I knew right now how to build a plant to do what we need, say it's going to produce a gigawatt of power, a thousand megawatts, a typical power plant. And it uses some new technology. I don't know, maybe it's clean coal, or it's solar, or it's wind, I don't know. And I got all the funding together and I built the plant and tomorrow I turn it on. And the next day, I turn on another such plant. And the next day, another such plant. It will take me 27 years to get 10 terawatts of power. That's just a piece of the current energy need.

So I need to have this enabling technology, the enabling science, I like to say miracles. I need them to happen sometime over the next 10 to 20 years if we're ever going to get to where we need to by the middle of the century.

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Clean Energy Initial Ideas: Teacher Instructions

The goal of this exercise is to have your students "expose" their current ideas about current energy consumption and "clean" energy production before they engage in learning activities that will explore these questions. You should let your students know that this is not a test of what they know and encourage them to makes guesses which they will be able to evaluate based on what they learn in the unit. You may also want to have your students share their ideas with the class (there are no "bad" ideas at this stage) and create a giant class worksheet of ideas. Students can then discuss whether or not they think each of these statements is true and why.

Write down your initial ideas about each question below and then evaluate how confident you feel that each idea is true.

1. **What are the top three sources of energy in the world today?**	**How sure are you that this is true?** Not Sure	Kind-of Sure	Very Sure
2. **What are some characteristics of clean energy?**	**How sure are you that this is true?** Not Sure	Kind-of Sure	Very Sure
3. **What are some current and future clean energy sources?**	**How sure are you that this is true?** Not Sure	Kind-of Sure	Very Sure

Name___________________________________ Date______________________ Period ______

Hybrid Cars, Solar Cells, and Nanoscience: Teacher Key

Think about the article you just read: Hybrid Cars, Solar Cells, and Nanoscience. Use what you learned from the reading to help you answer some of questions below.

1. A solar cell converts energy. What is the input of the conversion and what is the output of the conversion? (In other words, what does the solar cell convert?)

   Input: energy from the sun.
   Output: electricity.

2. What are the advantages of nanocrystalline ("dye-sensitized") solar cells when compared to silicon-based solar cells?

   Nanocrystalline cells use less expensive materials and are easier to manufacture. They are also more flexible, which allows them to be used in a wider range of applications.

3. In two to three sentences, describe how a hybrid car works.

   A hybrid car is able to capture energy lost during braking and convert it into electricity. The hybrid car has both a gasoline engine and an electric motor to make it move. It uses electrical energy from the batteries to drive the electric motor.

4. What do you think are advantages and disadvantages of the following energy sources? List one advantage and one disadvantage for each source.

	Advantage	Disadvantage
Nuclear power plant	Inexpensive, abundant energy	Waste materials are highly toxic and hard to dispose of
Hydroelectric dam	Inexpensive, abundant energy	Cost to build dam, negative impact on wildlife/ecosystem

5. In two to three sentences, describe the importance of solar energy.

   An incredible amount of energy from the sun hits the earth every day—enough to meet the world's energy needs many times over. If we could capture more of this energy with solar cells, we would have a clean, renewable energy source that would help move us away from fossil fuel use (and the pollution that goes with it).

Lesson 1:
Introduction to Clean Energy

Student Materials

Contents

Clean Energy Initial Ideas: Student Worksheet

Write down your initial ideas about each question below and then evaluate how confident you feel that each idea is true.

1. What are the top three sources of energy in the world today?	**How sure are you that this is true?** Not Sure	Kind-of Sure	Very Sure
2. What are some characteristics of clean energy?	**How sure are you that this is true?** Not Sure	Kind-of Sure	Very Sure
3. What are some current and future clean energy sources?	**How sure are you that this is true?** Not Sure	Kind-of Sure	Very Sure

Hybrid Cars, Solar Cells, and Nanoscience: Student Reading

Why Hybrid Cars?

Fossil fuels, such as oil, coal and gas are primary sources of energy in the world today, powering a range of machines from automobiles to power plants that generate electricity for our homes, schools and businesses. As we continue to burn **fossil fuels** as a primary energy source, we need to be thinking about the impact their use is having on the environment, as well as what their supply will look like in the next few decades. Fossil fuels come from the earth, are in limited supply, and have a detrimental impact on our environment (e.g. production of **greenhouse gasses**). We need to be thinking about what **alternative energy sources** we can turn to. In addition to looking at current and upcoming sources of energy, we can also consider energy conservation and increased **energy efficiency** as complementary methods of reducing our use of fossil fuels. One technology that is helping to increase the efficiency of one of our most popular fossil fuel-based machines, the automobile, is being employed more and more frequently by automobile manufacturers: **hybrid** technology. Hybrids, as they are often called, use a combination of gasoline and electricity to increase mileage and decrease fuel consumption.

What are Hybrid Cars?

The basic idea behind hybrid cars is to efficiently use as much energy as possible from the gasoline put into the car. Hybrids do this by capturing energy that is usually lost through braking, storing this energy, and then using the stored energy to supplement the gasoline engine. Unlike a typical gasoline-only car, hybrids conserve energy by **regenerative braking**.

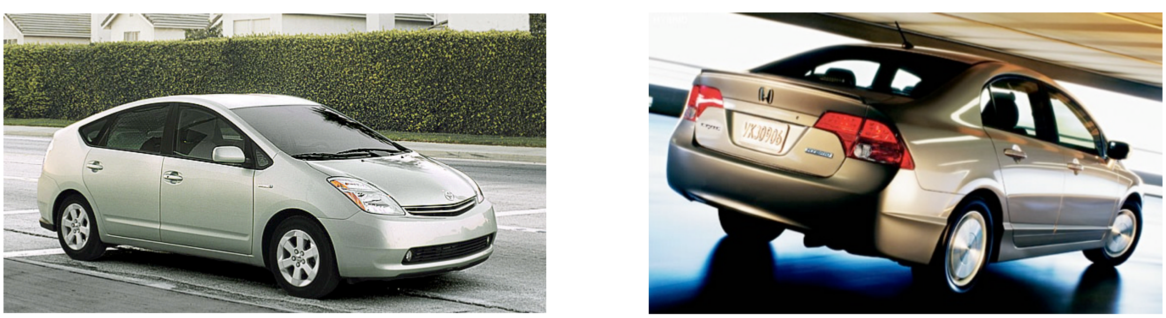

Figure 1. Two popular hybrid cars: Honda Civic Hybrid and the Toyota Prius [1, 2].

In a typical car, a gasoline engine is used to increase the speed of the car, and the braking system—specifically, the **brake pads**—are used to decrease the speed of the car. While decreasing speed, the brakes slow the car down by applying **friction** to the discs or drums attached to the car's wheels. What the brakes in your car do is convert **kinetic energy**—the motion of your car—into heat energy as the car slows down. Unfortunately, this heat energy is lost—it is not captured and reused to help power the car.

If you look at how energy is conserved, or the **conservation of energy**, a gasoline-only car converts **chemical potential energy** (the gasoline) into other energies such as kinetic energy (the motion of the car), some electrical energy (for things like the lights and the radio), and heat (engine heat, brake heat). However, only about 20-25% of the energy in the gasoline is converted into moving the car and powering the electrical systems. The rest is lost as heat. This is like saying that for every 10 gallons of gasoline you put into your car, only about 2.5 gallons (one-fourth) of that gas goes towards the car's movement and electrical systems. The rest is basically lost energy to the environment. This loss in energy is not by design, but rather a natural constraint with gasoline engines (and to some extent to all engines.)

A hybrid car recaptures about 10% of the total energy, boosting the efficiency up to about 35%. This may not seem like a lot, but a 10% increase in efficiency (from 25% for a typical car to 35% for a hybrid) is equivalent to reclaiming about a gallon of gas for every 10 gallons you put in the tank. Hybrids use additional "tricks" such as using lightweight materials, aerodynamics, low-rolling resistance tires, and shutting the engine off when not in use, to increase miles per gallon [3].

How Do Hybrid Cars Work?

Hybrid technology, as used in automobiles, refers to using a combination of gasoline and electricity to power the car. Since hybrid cars do not typically require being plugged in at night, how do the batteries in the car get recharged? *By using the brakes and the generator.* Looking at the brakes, this system in a hybrid car has been designed to capture energy used to slow the car down. This type of system is often called a **regenerative braking system** since it captures energy that otherwise would be lost as heat, storing this energy in the car's batteries, and then using this energy.

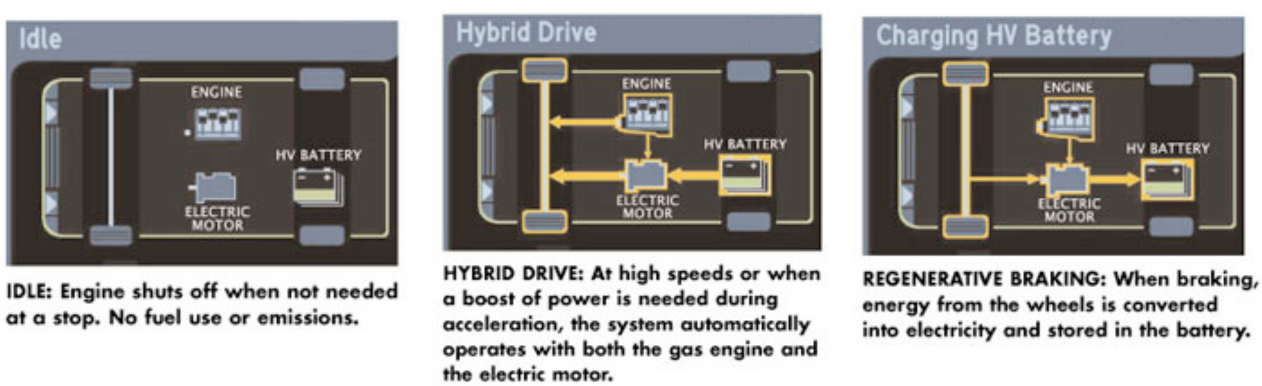

Figure 2. Three stages in one type of hybrid drive system: Idle, Hybrid Drive, and Charging. In "hybrid drive," both the electric motor and the gasoline engine power the car. In "charging" mode, when the brakes are applied the electric motor spins in the opposite direction, thus acting like a generator to charge the batteries and slow down the car [4].

Instead of using brake pads like in a traditional, gasoline-only car, a hybrid car employs an **electric motor**. As you press down on the brake pedal to slow down, the electric motor (1) provides resistances to the wheels so the car will slow down, and (2) generates electricity to charge the batteries. The resistance to slow the car down comes from the electric motor acting as a **generator**: generators are hard to turn (they require you to do work) since they basically take your mechanical energy (kinetic energy or energy of motion) and turn it into electrical energy. So instead of energy being lost as heat when you brake, the energy is turned into electricity and stored in the rechargeable battery system.

The energy from the batteries is used to power an electric motor to supplement the gasoline engine when needed. The car can have a smaller gasoline engine since the specially designed engine can seamlessly take either gasoline or electricity as "input" to make the car move. This results in a more efficiently-running car that is "cleaner" in the sense that it burns less gasoline and has fewer **emissions** than a typical car.

Why Not an Electric-Only Car?

So why not just have an electric car instead of a gas engine altogether, since you can just plug an electric car in at night and "fill up" with electricity? This is a good question. Electric cars do exist, most notably the GM EV1, which you may have seen on the road. Electric cars basically have zero emissions, meaning that no pollutants are generated and emitted from the car while driving. Electric cars are very clean in this sense—they don't pollute when you drive them. But it is important to look a bit closer at how "clean" electric-only cars are, really. When you plug in an electric car (or anything that uses electricity), where does that electricity come from? How is it produced?

Where Does Our Electricity Come From?

Electric energy that comes into your home or into your neighborhood coffee shop or grocery store through the electrical lines typically comes from a variety of sources. These sources include coal-burning and natural gas power plants ("electric plants"), hydroelectric dams ("water power"), nuclear power plants, and, to a much lesser extent, wind generators and solar panels.

Each of these energy sources has plusses and minuses. For example, the main advantage of coal-burning power plants is that they are relatively cheap to operate, since coal is still a fairly abundant energy source in the U.S. and China. However, coal-burning power plants rely on the burning of fossil fuel (like coal) to generate electricity. When fossil fuel is burned, it releases green house gases such as carbon dioxide (CO_2) and pollutants such as sulfur dioxide (SO_2) and nitric oxides (NO_X).

In contrast, solar power produces very clean energy when operated—there are no pollutants created. But solar panels are expensive to make, and greenhouse gases are produced during their manufacture since the manufacturing process needs electricity. As a result, the cost of the energy produced through solar technology is relatively expensive––several times more expensive than produced at a coal-burning power plant.

What is Solar Energy?

Solar energy is energy that comes from the sun. Using a technology called a **solar cell,** or **photovoltaic cell**, energy from the sun can be converted into electricity. Solar cells are able to convert some of the energy from the sunlight hitting them into usable electricity.

You may have seen solar cells in a calculator or on the top of a building. If used on a large scale, solar cells can help in satisfying world energy demand by capturing a portion of the incredible amount of solar energy hitting the earth's surface on a daily basis.

Figure 3 shows the breakdown of energy consumed in the U.S. in 1997 by source [5]. As you can see, petroleum—fossil fuel products such as gasoline and oil—is the most heavily consumed energy source in the United States. Natural gas (the kind you use to power a gas stove or gas water heater) and coal are also heavily used. Other renewable sources, such as wind power and hydroelectric power (electricity produced from the movement of water), are a much smaller part of the puzzle, as is nuclear.

On the far right of the graph is solar, making up a very small fraction of the energy *used* in the United States. However, the *supply* of solar energy from the sun far exceeds all the other energy supplies (gasoline, coal, natural gas, etc). If we included a bar on the chart that represented the amount of energy from the sun that reaches the United States, the bar would be about 400 feet tall! Quite a bit of energy from the sun hits the earth every day—enough to satisfy our energy needs many times over.

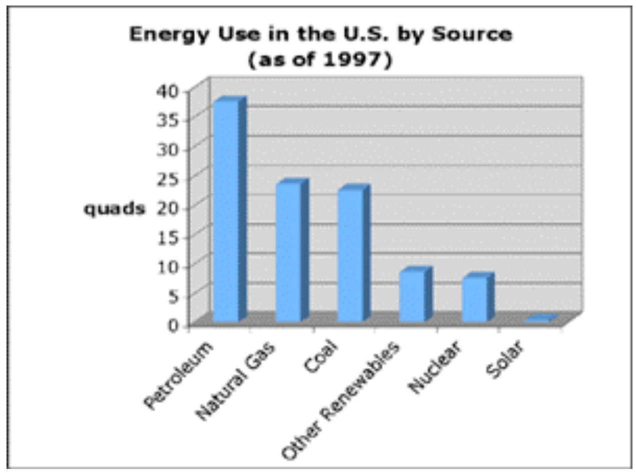

Figure 3. If the amount of energy hitting the U.S. from the sun were shown as a bar on this graph, it would be 400 feet tall! (A "quad" is 10^{15} Btu's.)

If we could effectively collect solar energy and turn it into a usable form, like electricity, we could easily meet the entire world's need for clean, renewable energy.

Figure 4 shows the relative amount of the earth's surface that needs to be covered with solar panels to meet the world's current energy demands. The six black dots represent a hypothetical set of land areas where solar panels could be installed. The total area of these panels is less than one-tenth the total area of the United States. This is a relatively small proportion of the earth's land area to dedicate to solar panel installation, but there are political and technical constraints that would need to be overcome to implement such a large area of solar cells.

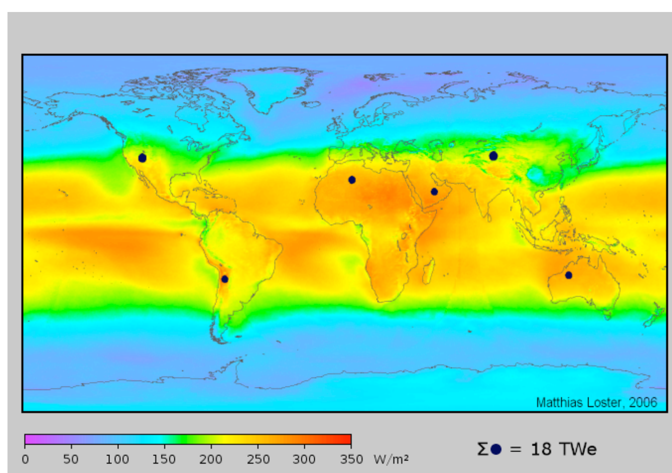

Figure 4. Solar power systems installed in the dark areas could provide a little more than the world's current total primary energy demand [6].

Looking closer at the technology, many current solar cells are made up of single-crystal silicon—the same material used in the processor chips in your computer [7]. Unfortunately, the use of single-crystal silicon makes solar cells expensive to produce. As you may have guessed, the high cost of silicon-based solar cells has negatively impacted their widespread use.

Silicon (Si^{14}) is a **semiconductor** used in circuits and solar cells because:

- It allows electrons to flow through it in very controlled ways,
- It can be heated to high temperatures which enables the creation of circuits and solar cells,
- It can easily be grown in a furnace, thus enabling large-scale production, and
- SI is cheap and widely available.

Can Nanoscience Help Make Better Solar Cells?

Yes! Another type of solar cell, called a nanocrystalline (or sometimes “dye-sensitized”) solar cell, also converts solar energy into electricity, but is less expensive to make due to the low cost of materials. These types of cells were discovered in 1991 and are still in their infancy—researchers are currently investigating ways to optimize their production and efficiency, so their use is not yet widespread [8, 9]. One reason for the limited use of nano solar cells is that their efficiency is lower than that of conventional silicon solar cells due to the difficulty in harnessing the electrons to generate an electrical current [10].

Nanocrystalline solar cells use a mixture of very small (nanoscale-size) titanium dioxide particles [11], dye molecules (e.g. crushed blueberries), and an iodide solution. By using these relatively inexpensive components, nanocrystalline solar cells are easier and cheaper to make than traditional silicon-based solar cells. In addition, they tend to be flexible, meaning they can be used in a wider range of applications than their stiffer, silicon-based counterparts.

Solar Cell Animations
The Clean Energy unit includes two animations of what happens when sunlight shines on silicon and nanocrystalline solar cells. You can see these models on the NanoSense web site at http://nanosense.org/activities/cleanenergy/solarcellanimation.html

Nanocrystalline solar cells are cheaper to make than silicon-based solar cells and thus have the potential of becoming more widely used. As researchers continue to investigate better ways to make nanocrystalline solar cells, their production and use might increase to the point where they are accepted as a viable, alternative energy source in the world.

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Glossary

Term	Definition
fossil fuels	A hydrocarbon deposit, such as petroleum, coal, or natural gas, derived from living matter of a previous geologic time and used for fuel. [12]
greenhouse gasses	Gasses such as water vapor, methane, carbon dioxide, and nitrous oxide that contribute to the absorption of sun energy by the earth (the "greenhouse effect"). Some amount of greenhouse effect is part of the earth's natural ecology. However, the greenhouse effect has been increased due to such human factors as the burning of fossil fuels. [13]
alternative energy sources	Any of various renewable power sources to use in place of fossil fuels and uranium. Some alternative energy sources include solar energy, wind power, tidal power, wave power, hydroelectric power, and geothermal energy, and nuclear fusion. [14]
energy efficiency	Energy efficiency is the ratio of useful energy output to energy input. In reference to a gasoline engine, useful output would be moving the car forward (kinetic energy) and powering the electrical systems (electrical energy), and the input would be the gasoline (chemical energy). The efficiency is the ratio of output to input—the greater the amount of input energy converted into useful output energy, the higher the "energy efficiency".
hybrid	In terms of an automobile, "hybrid" refers to the car being driven by a mix of engine types: both a gasoline engine and an electric motor.

brake pads	Brake pads are blocks of material that apply friction to the disc in a disc brake system. In a car they are used to slow the car down.
friction	Friction is the force that opposes the relative motion or tendency of such motion of two surfaces in contact. In other words, it is the force between two surfaces that are moving and in contact with each other, such as between a brake pad and spinning disc, between a plate sliding along a table, between a moving tire and the road. At its core, friction is the electrostatic interactions/forces between atoms and molecules. [13]
kinetic energy	Form of energy that an object has due to its motion. The kind of motion may be translation (motion along a path from one place to another), rotation about an axis, vibration, or any combination of motions. The total kinetic energy of a body or system is equal to the sum of the kinetic energies resulting from each type of motion. The kinetic energy of an object depends on its mass and velocity. For instance, the amount of kinetic energy KE of an object in translational motion is equal to one-half the product of its mass m and the square of its velocity v, or $KE = \frac{1}{2} mv^2$, provided the speed is low relative to the speed of light. [14]
conservation of energy	The principle of conservation of energy states that energy cannot be created or destroyed, although it can be changed from one form to another. Thus in any isolated or closed system, the sum of all forms of energy remains constant. The energy of the system may be interchanged among many different forms—mechanical, electrical, magnetic, thermal, chemical, nuclear, and so on, but the total amount of energy remains constant. [12]
chemical potential energy	Chemical potential energy is a form of potential energy related to the structural arrangement of atoms or molecules. This arrangement may be the result of chemical bonds within a molecule or otherwise. Chemical energy of a chemical substance can be transformed to other forms of energy by a chemical reaction. For example, when a fuel is burned the chemical energy is converted to heat, same is the case with digestion of food metabolized in a biological organism. Green plants transform solar energy to chemical energy through the process known as photosynthesis, and electrical energy can be converted to chemical energy through electrochemical reactions. [13]
regenerative braking system	A regenerative braking is a system which allows a vehicle to recapture part of the kinetic energy that would otherwise be lost to heat when braking and make use of that power either by storing it for future use or feeding it back into a power system for other vehicles to use. [13]

electric motor	A machine that converts electrical energy into mechanical energy. When an electric current is passed through a wire loop that is in a magnetic field, the loop will rotate and the rotating motion is transmitted to a shaft, providing useful mechanical work. [12]
generator	A generator is a machine that converts mechanical energy into electrical energy. It is, in effect, an electric motor in which you turn to generate electricity. It is used in hybrid cars to convert the motion of the car (kinetic energy) into electricity.
emissions	In common usage, emission is most often the giving off of gases from industrial processes and the engine exhausts of transport vehicles (automobiles, trucks, airplanes, trains and ships). As they occur on an industrial scale, even relatively harmless gases can have an undesired effect (such as carbon dioxide contributing to the greenhouse effect). [13]
solar cell/ photovoltaic cell	Any device that directly converts the energy in light into electrical energy. Solar cells do not use chemical reactions to produce electric power, and they have no moving parts. All solar cells are designed for converting sunlight into electricity. In large arrays, which may contain many thousands of individual cells, they can function as central electric power stations analogous to nuclear, coal-, or oil-fired power plants. [14]
semiconductor	Semiconductors are solid materials with a level of electrical conductivity between that of insulators and conductors. Because of their ability to control electrical currents, semiconductors have been used in the manufacture of a wide range of electronic devices—including computers—that changed American life during the second half of the twentieth century. [12]

Name__________________________________ Date______________________ Period ______

Hybrid Cars, Solar Cells, and Nanoscience: Student Worksheet

Think about the article you just read: Hybrid Cars, Solar Cells, and Nanoscience. Use what you learned from the reading to help you answer some of questions below.

1. A solar cell converts energy. What is the input of the conversion and what is the output of the conversion? (In other words, what does the solar cell convert?)

2. What are the advantages of nanocrystalline ("dye-sensitized") solar cells when compared to silicon-based solar cells?

3. In two to three sentences, describe how a hybrid car works.

4. What do you think are advantages and disadvantages with the following energy sources? List one advantage and one disadvantage for each.

	Advantage	Disadvantage
Nuclear power plant		
Hydroelectric dam		

5. In two to three sentences, describe the importance of solar energy.

Lesson 2:
Solar Energy and Nanoscience

Teacher Materials

Contents

Solar Energy and Nanoscience: Teacher Lesson Plan

Orientation

This lesson introduces students to solar energy and gives an overview of current solar-cell technologies. In particular, traditional silicon-based solar cells are described and compared with more current nanocrystalline solar cells. This lesson highlights the importance of solar technologies as part of a clean, renewable world energy solution.

- The Clean Solar Energy PowerPoint provides an introduction to solar energy and solar technologies, including silicon-based and nanocrystalline solar cells.
- Silicon and Nanocrystalline Solar Cell Animations provides an interactive animation and worksheet activity to help your students understand the differences between two types of solar cells.
- Solar Cell Technology Teacher Reading provides background on how two types of solar cells work. This teacher reading is recommended prior to presenting the Day 2 solar slides and activities.
- The Nanocrystalline Solar Cell Lab Activity is a one to two day hands-on lab activity that gives students the opportunity to build and test an actual nanocrystalline solar cell.
- The Reflecting on the Guiding Questions Worksheet asks students to connect their learning from the activities in the lesson to the overall driving questions of the unit. Students can complete this worksheet individually or in pairs.

Essential Questions (EQ)

What essential questions will guide this unit and focus teaching and learning?

(Numbers correspond to learning goals overview document

3. What are current and projected global energy demands?
4. How do newer, nanotechnology-influenced solar cells work, and how do they differ from traditional solar cells?

Enduring Understandings (EU)

Students will understand:

(Numbers correspond to learning goals overview document)

2. Nanoscience could enable important breakthroughs in solar energy technology through low cost, novel energy conversion mechanisms.
3. Surface area to volume ratio is a function of particle size and shape. Increasing surface area normally increases the rate of reaction because there are more sites available for simultaneous reaction.
4. Energy is neither created nor destroyed—it can only be converted into different forms.

Key Knowledge and Skills (KKS)

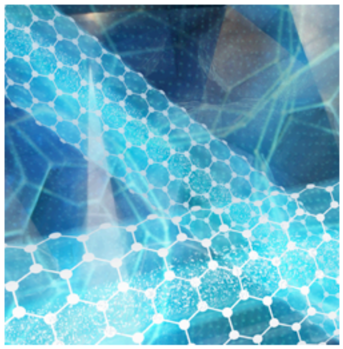
Students will be able to:

(Numbers correspond to learning goals overview document)

2. Explain what silicon-based solar cells are and how they function.
3. Explain what nanocrystalline (nanotechnology-influenced) solar cells are, how they function, and how surface area to volume ratio affects their efficiency in converting light energy to electricity.
4. Compare the main advantages/disadvantages of silicon-based solar cells and nanocrystalline solar cells.

Solar Energy and Nanoscience Timeline

Day	Activity	Time	Materials
Day 1 (50 min)	Show the Clean Solar Energy PowerPoint slides, using the question slides and Teacher's Notes to start class discussion. You may also want to read the "Solar Cell Background Teacher Reading" before class.	30 min	Clean Solar Energy PowerPoint Slides & Teacher Notes Solar Cell Background Teacher Reading Computer and projector
	Silicon and Nanocrystalline Solar Cell Animations: Student Instructions. Students can work in pairs or groups three interacting with the animations and discussing/completing the animation worksheet.	15 min	Copies of Silicon and Nanocrystalline Solar Cell Animations: Student Instructions Silicon and Nanocrystalline Solar Cell Animations: Teacher Instructions
	Homework: Hand out the Nanocrystalline Solar Cell Lab Activity: Student Instructions. Spend 5 minutes reading through the lab procedure with your students so they are clear about what will be happening in the lab over the next day or two.	5 min *15 min home*	Copies of Nanocrystalline Solar Cell Lab Activity: Student Instructions
Day 2 (50 min)	Students follow the lab procedure handed out and discussed the previous day. Depending on the preparations the teacher has made for the lab, the students will either spend one or two days working on the lab. See the Teacher Instructions for details on how to make the lab either a one-day or two-day activity.	50 min	(See the Nanocrystalline Solar Cell Lab Activity: Teacher Instructions for information on where to get the Solar Cell Kit lab)
	Homework: Read the Student Reflection on the Guiding Questions worksheet and answer the questions.	*15 min*	Copies of Reflection on the Guiding Questions: Student Worksheet
Day 3 (50 min) (optional)	Bring the class together to have students share their reflections with the class. This is also a good opportunity for you to address any misconceptions or incorrect assumptions from students that you have identified in the unit up till now.	10 min	
	If you have chosen to do the Nanocrystalline lab over a two-day period, use the rest of today's class session to complete the lab.	40 min	



Clean Solar Energy

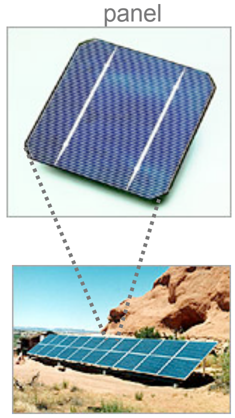
The impact of nanoscale science on solar energy production

NanoSense
the basic sense behind nanoscience

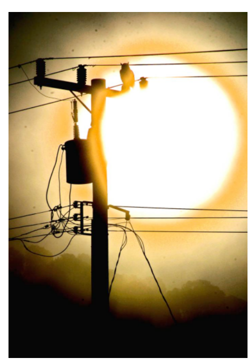
What is Solar Energy?

- Energy produced by the sun
- Clean, renewable source of energy
- Harnessed by solar collection methods such as solar cells
- Converted into usable energy such as electricity

Photovoltaic (solar) panel



Set of solar panels

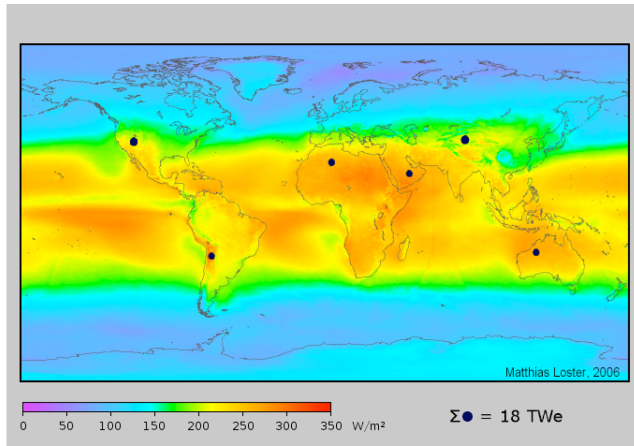


Sun and electrical power lines

Sources: http://www1.eere.energy.gov/solar/pv_systems.html
http://thomashawk.com/hello/209/1017/1024/Staring%20at%20the%20Sun.jpg

Energy from the Sun is Abundant

- Solar power systems installed in the areas defined by the dark disks could meet the world's current total energy demand



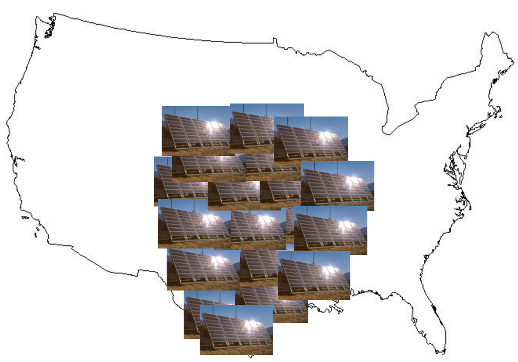
Source: http://www.ez2c.de/ml/solar_land_area/

Current U.S. Energy Demand

- The US consumes ~25% of the world's energy, but has only 4.5% of its population
- Solar cells would need to cover an area comparable to the size of Texas to meet US energy demand today

Sources: http://energy.cr.usgs.gov/energy/stats_ctry/Stat1.html
http://www.census.gov/main/www/popclock.html

Projected U.S. Energy Demand in 2050



- To meet projected U.S. demand in 2050, solar cells would need to cover approximately one third of the U.S.

Sources: http://energy.cr.usgs.gov/energy/stats_ctry/Stat1.html
http://www.census.gov/main/www/popclock.html

Solar Panel Use Today

- Large companies like Google, Walmart, and Microsoft use solar energy to partially power some of their facilities

Solar panels on Microsoft building

Solar panels being tested on Walmart store

Sources: http://i.n.com.com/i/ne/p/2006/IMG_5396_550x367.jpg
http://www.solarwall.de/assets/images/Walmart_SW.jpg

Photovoltaic Solar Cells

- **Generate electricity directly from sunlight**
- **2 Main types:**
  - Single-crystal silicon (traditional)
    - Widespread
    - Expensive to manufacture
  - Dye-sensitized ("nano")
    - Newer, less proven
    - Inexpensive to manufacture
    - Flexible

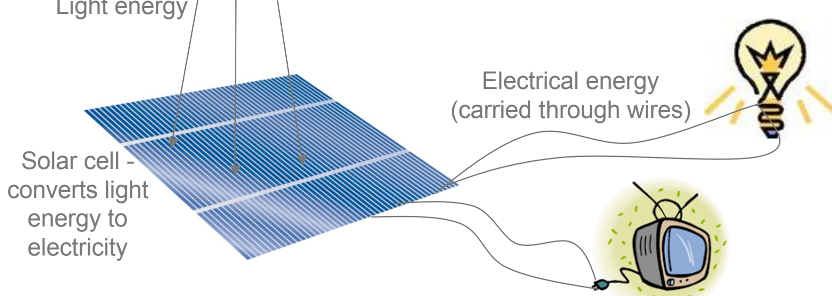
Silicon-based solar cell

Dye-sensitized solar cell

Sources: http://www.elp.uji.es/juan_home/images/solar_cell/flex1.JPG
http://www.wisconsun.org/images/siemen_cell.jpg, http://en.wikipedia.org/wiki/Solar_cell

Solar Cells are Converters of Energy…

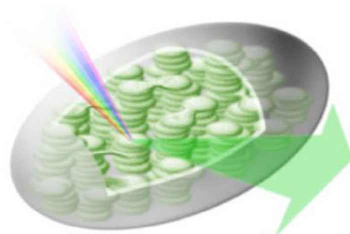
- **Solar cells are devices that take light energy as input and convert it into electrical energy**



Sources: http://www.econedlink.org/lessons/EM189/images/cartoon_tv.gif
http://emmagoodegg.blogs.com/thebeehive/images/lightbulb.jpg, http://www.torpedowire.com/solar.htm,
http://www.uoregon.edu/~stiedeke/a3/assignment03/a3/assignment_images/cartoon-sun.jpg

…But Not All Energy is Converted

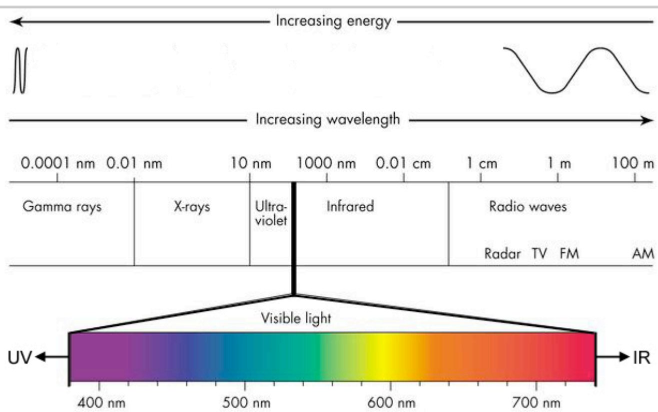
- Like chloroplasts in plants, solar cells can only absorb specific wavelengths of light.
- In both, light that isn't absorbed is either transmitted through or reflected back.
- Whether a certain wavelength of lights gets absorbed depends on its energy.



Chlorophyll molecules absorb blue and red light, but reflect green light

Source: http://ebiomedia.com/prod/cyclops/images/image004.jpg

A Little Background on Light



- **Different colors of light have different wavelengths and different energies**

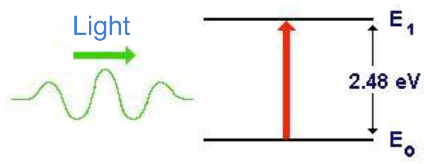
Source: http://www.mhhe.com/physsci/astronomy/arny/instructor/graphics/ch03/0305.html

NanoSense 11

Absorption of Light by *Atoms*

- Absorption occurs only when the energy of the light equals the energy of transition of an electron

Single electron transition in an isolated atom

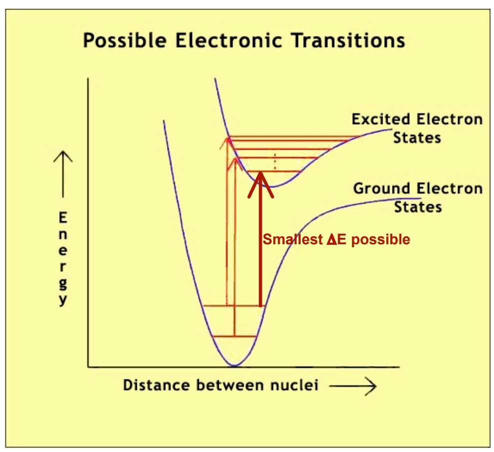


Sources: http://members.aol.com/WSRNet/tut/absorbu.htm, http://csep10.phys.utk.edu/astr162/lect/light/absorption.html

NanoSense 12

Absorption of Light by *Molecules*

- Molecules have multiple atoms bonded together
- More energy states in molecules than atoms
- More electron "jumps" possible - light with a range of frequencies are absorbed

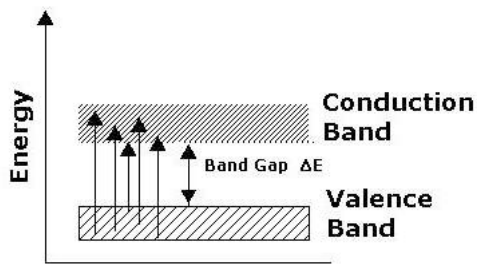


Source: Image adapted from http://www.3dchem.com/molecules.asp?ID=135#

NanoSense 13

Absorption of Light by *Ionic Compounds*

- **Electrons can jump between "bands"**
- **Incident light with energy ≥ than the "band gap" energy can be used to excite the electrons**

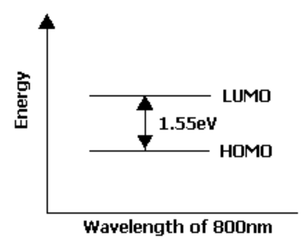


Source: Image adapted from http://www.3dchem.com/molecules.asp?ID=135#

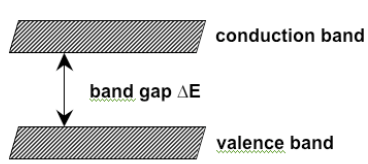
NanoSense 14

So What Does this Mean for Solar Cells?

- **In dye-sensitized solar cells…**
  - Talk about highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO)



- **In single-crystal silicon solar cells…**
  - Talk about "conduction band" (excited states) and "valence band" (ground states)



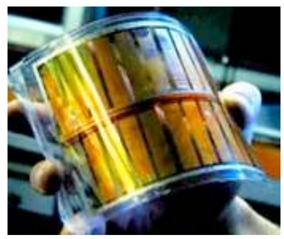
Source: Original Images

2-T11

A Closer Look at Solar Cells

- How do traditional, silicon-based solar cells and newer, dye-sensitized solar cells work?
- What are the advantages and disadvantages of each type of cell?

Silicon-based solar cell

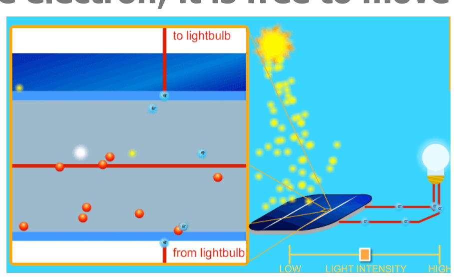


Dye-sensitized solar cell

Sources: http://www.norfolksolar.co.uk/img/system.gif
http://www.powerlight.com/newsletters/news_issue/3/newsletter_industry.htm

How a Silicon-Based Solar Cell Works

- Light with energy greater than the band gap energy of Si is absorbed
- Energy is given to an electron in the crystal lattice
- The energy excites the electron; it is free to move
- A positive "hole" is left in the electron's place
- This separation of electrons and holes creates a voltage and a current



Click image to launch animation (requires web access)

Source: http://nanosense.org/activities/cleanenergy/solarcellanimation.html

NanoSense 17

Silicon-Based Solar Cell Attributes

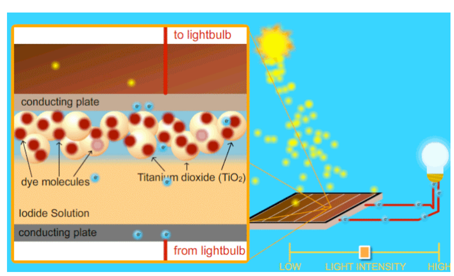
- **Expensive**
  - Made in high vacuum at high heat
  - High manufacturing costs
- **Need TLC**
  - Fragile, rigid, thick
- **Long return on investment**
  - Takes 4 years to produce energy savings equivalent to cost of production

Source: http://www.powerhousekids.com/stellent2/groups/public/documents/pub/phk_ee_re_001505-2.gif

NanoSense 18

How a Dye-Sensitized Cell Works

- **Light with high enough energy excites electrons in dye molecules**
- **Excited electrons infused into semiconducting TiO_2, transported out of cell**
- **Positive "holes" left in dye molecules**
- **Separation of excited electrons and "holes" creates a voltage**



Click image to launch animation (requires web access)

Source: http://nanosense.org/activities/cleanenergy/solarcellanimation.html

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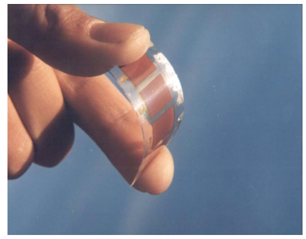
Dye-Sensitized Solar Cells

- **Relatively inexpensive**
  - Made in non-vacuum setting mainly at room temperature
  - Relatively simple manufacturing process
- **Need little TLC**
  - Thin, lightweight, flexible
- **Short return on investment**
  - Takes approx 3 months to produce energy savings equivalent to cost of production



Source: http://www.imo.uhasselt.be/polytech/images/zonnecel1.jpg

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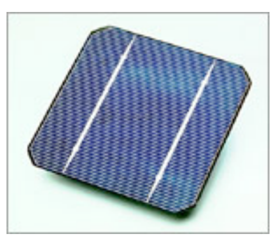
Dye-Sensitized and Silicon-based Solar Cells Compared

- **Dye-Sensitized**
  - Relatively inexpensive
  - Need little TLC
  - Short return on investment
- **Traditional**
  - Expensive
  - Need TLC
  - Long return on investment



Sources: http://www.imo.uhasselt.be/polytech/images/zonnecel1.jpg
http://www.norfolksolar.co.uk/img/system.gif

Solar Electric Power Plants

- **Harness solar power to generate electricity**
- **Main types:**
  - Solar thermal energy
    - Has mirrored surface that reflects sunlight to heat up liquid to make steam to generate electricity
  - Photovoltaic
    - Uses photovoltaic cells that absorb direct sunlight (as discussed previously)

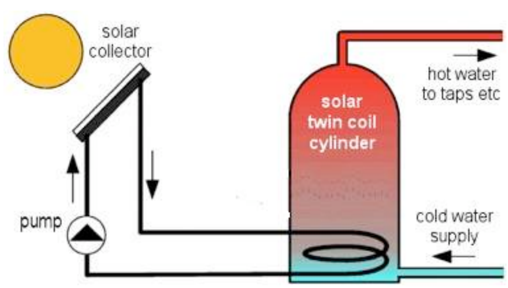
Array of mirrored solar collectors at FPL Energy site in California

Concentrated solar collector (parabolic)

Sources: http://en.wikipedia.org/wiki/Solar_energ
http://www.fplenergy.com/portfolio/solar/facts.shtml#glance

Solar Heating Systems

- **Direct heating of fluid; no conversion to electricity**
- **Components**
  - solar thermal collectors
  - fluid system to move heat (not electricity)
  - reservoir to stock heat for later use
- **Common uses**
  - Heat water for home or pool



Example system with water heated by solar collector and used to supplement hot water radiator

Source: http://www.norfolksolar.co.uk/img/system.gif

NanoSense 23

Wind Energy *is* Solar Energy

- Wind is driven by solar heating
- Largest and fastest growing solar energy conversion system

Wind “farm” in California

Wind turbines

Sources: http://p2library.nfesc.navy.mil/issues/emergejan2007/wind_turbine.jpg
http://science.howstuffworks.com/wind-power1.htm

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Important Summary Questions

- What are clean and renewable energy sources?
- What are current and projected global energy demands?
- How do newer, nanotechnology-influenced solar cells work, and how do they differ from traditional solar cells?

Clean Solar Energy: Teacher Notes

Overview

This series of slides discusses solar as an alternative energy source. It describes what solar energy is, and highlights several solar technologies, including nanocrystalline ("nano") solar cells.

Slide 1: Title Slide

Consider beginning the slide presentation by posing a few questions posed to your students: What are some things you know about solar energy? Where have you seen it used? What are some possible positive and the negative aspects of solar energy?

Slide 2: What is Solar Energy?

Solar cells, also referred to as "photovoltaic" cells, are devices that covert light energy into electricity. This energy conversion is "clean" (no pollutants produced in the process), although with any energy conversion system the environmental and financial costs of developing and producing the technology have to be taken into account. Until recently, their use has been limited due to high manufacturing costs and the high cost of single-crystal Si. One cost effective use has been in very low-power devices such as calculators with LCDs. Another use has been in remote applications such as roadside emergency telephones, remote sensing, and limited "off grid" home power applications. A third use has been in powering orbiting satellites and other spacecraft [1].

Slide 3: Energy from the Sun is Abundant [2]

Solar power systems installed in the areas defined by the dark disks could provide a little more than the world's current total primary energy demand (assuming a conversion efficiency of 8 %). That is, all energy currently consumed, including heat, electricity, fossil fuels, etc., would be produced in the form of electricity by solar cells. The colors in the map show the local solar irradiance averaged over three years from 1991 to 1993 (24 hours a day) taking into account the cloud coverage available from weather satellites. The following table lists the locations in the map to give an idea of land area requirements, although the particular scenario shown is suboptimal for many political and technical reasons.

Location (Desert)	Irradiation (W/m^2)	Area Required (km^2)
Africa, Sahara	260	144,231
Australia, Great Sandy	265	141,509
China, Takla Makan	210	178,571
Middle-East, Arabian	270	138,889
South America, Atacama	275	136,364
U.S.A., Great Basin	220	170,455

Slide 4: Current U.S. Energy Demand

The US consumes approximately 25% of the world's energy, but only has 4.5% of the world's population (U.S. population: 300 million people; World population: 6.5 billion people.) Solar cells would have to blanket a large area to meet current demands.

Note: Explain to your students that the relative size comparison between the solar panels and the land area of the U.S. is *very approximate*. It is meant only to convey the general idea that you'd need to cover quite a bit of the U.S. with solar panels to generate enough energy to meet projected needs.

Slide 5: Projected U.S. Energy Demand in 2050

These projected figures are based on a talk by Richard Smalley in 2005. He explains that the current world need is approximately 15 Terawatts, and the 2050 projected need is 30 to 60 Terawatts. The US consumes approximately 25% of this, or a projected need in 2050 of about 8 to 15 Terawatts.

Explain to your students that conventional solar cells are currently expensive to produce and limited in their efficiency. If we can reduce consumption or improve solar cell efficiency so that the cost per kilowatt-hour is comparable to current fossil fuel rates, solar energy may become a more integrated part of our energy plan in the future. Note also that solar energy may not provide a complete solution, but rather is part of the solution along with other alternative energy sources.

Slide 6: Solar Panel Use Today

This slide highlights the fact that large companies are starting to look at alternative energy sources to help power their operations. The following is a short article on Wal-mart's plans to start using solar and wind technologies to support the functioning of their business. If you like, you can read this article to your class or select the highlights.

"Wal-mart has announced that energy efficiency and renewable energy such as roof solar panels are part of its corporate goals for its U.S. stores. Wal-Mart's Chief Executive Officer Lee Scott over the next three years he wants to get 100 percent of its energy from renewable sources, cut energy use in stores by 30 percent, and cut fuel consumption in its truck fleet by 25 percent. A test store in Texas has been using solar panels and Wal-Mart's truck fleet is being outfitted with plastic skirts to cut wind resistance. Adding one mile per gallon to the fleet can save the mega-retailer $2 million a year, according to Scott. "If Wal-Mart was a city, they'd be No. 5 in country, so the company's leadership is very important," says Amory Lovins, who heads the Rocky Mountain Institute, an energy think tank in Snowmass, Colo. "If they help introduce similar efficiencies and green practices throughout their supply chain, it could have a huge effect." [5]

Slide 7: Photovoltaic Solar Cells

There are two main types of solar cells: p-n junction cells (silicon-based) and non-p-n (dye-sensitized) cells. The following slides describe these types of cells and the advantages and disadvantages of each type.

Silicon solar cell efficiency (that is, the percentage of light that shines on a solar cell that is converted to electricity) varies from 6% for silicon-based solar cells to 40% or higher with multiple-junction research lab cells. The highest efficiency cells have not always been the most economical to produce, even though they are better at converting light into electricity.

Slide 8: Solar Cells are Converters of Energy…

This slide simply stresses the idea that solar cells don't make electricity, but instead are devices that convert energy from one form to another – light energy to electrical energy. You can also point out other "converter" devices such as a stereo speaker (electrical energy→sound energy), a motor (electrical energy→mechanical energy), or a battery (chemical potential energy→electrical energy). You might also want to ask your students why we have these converter devices in the first place (basically to convert energy into more useful forms for the given need.)

Slide 9: …But Not All Energy is Converted

Solar cells are able to absorb light only if the light has a certain amount energy to promote valence electrons into an higher energy state (or band depending on the type of solar cell.) Energy that is not absorbed either goes through the cell (transmittance) or bounces off the cell (reflection.)

In both the chlorophyll and the solar cell, energy is being absorbed from light, causing an electronic transition. This energy is captured by the electrons and therefore can be harnessed and used.

Slide 10: A Little Background on Light

This diagram provides a visual representation of the electromagnetic spectrum for your students. They may have seen similar electromagnetic spectrum representations previously. Point out that the visible range—the part of the electromagnetic spectrum that we can see with our eyes—is a relatively small slice that lies in the middle of the larger electromagnetic spectrum. Also point out that the energy of the electromagnetic wave increases as you go left and that smaller wavelengths correlate with high energies (and can typically penetrate more and more materials (e.g. lead (Pb) can block x-rays but not gamma rays.)

Point out to your students that while looking specifically at the visible light range, the higher energy (shorter wavelength) waves are to the left in the *violet* region, whereas the lower energy (longer wavelength) waves are in the *orange/red* region.

[Alyssa has new graphic for this slide]

Slide 11: Absorption of Light by *Atoms*

This slide focuses on the concept of atoms having discrete energy states or "jumps" that electrons can make. This slide sets up the discussion of silicon-based solar cells having a limited number of energy state transitions when compared to the energy transitions of molecules (discussed in next slide)

Slide 12: Absorption of Light by *Molecules*

This slide focuses on the idea that because molecules have multiple atoms bonded together, they tend to have many more energy states available. This slide relates closely to energy transitions in the dye-sensitized solar cells.

Slide 13: Absorption of Light by *Ionic Compounds*

This slide focuses absorption of light by ionic compounds, which is what happens in a traditional, single-silicon solar cell. In the single-crystal silicon solar cell, electrons have to have a minimum "band gap" energy before they can be released. Electrons can jump from anywhere in the valence band to anywhere in the conduction band, so incident light with an energy equal to or greater than the band gap energy can be used to excite the electrons. The valence band and the conduction band overlaps several Si atomic orbitals. For the electrons to jump between the valence band and the conduction band, the valence band has to be partially empty and the conduction band has to be partially full.

Slide 14: So What Does this Mean for Solar Cells?

In this slide, make reference back to the teacher reading on the two types of solar cells. Highlight with your students the differences between highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) in relation to dye-sensitized solar cells, as well as between HOMO/LUMO and band gap, conduction band, and valence band in single crystal silicon solar cells.

Slide 15: A Closer Look at Solar Cells

This slide sets up a comparison of two solar cell technologies, silicon-based solar cells and dye-sensitized solar cells, which are discussed in detail in the following slides.

Slide 16: How a Silicon-Based Solar Cell Works

When a light strikes a single crystal silicon solar cell, one of three things can happen:

1. The light can pass straight through - this happens for light that is less than the band gap energy for silicon
2. The light can reflect off the surface.
3. The light can be absorbed by the silicon, exciting electrons and creating electron-hole pairs

We are most interested in situation 3—when light is absorbed, its energy is transferred to an electron in the crystal lattice. This electron is in the valence band, and is tightly bound in covalent bonds between neighboring atoms, and hence unable to move far. The energy given to it by the light "excites" it into the conduction band, where it is free to move around within the semiconductor.

The covalent bond that the electron was previously a part of now has one less electron. This is called a "hole." The presence of a missing covalent bond allows the bonded electrons of neighboring atoms to move into the hole, leaving another hole behind, and in this way a hole can move through the lattice. Thus, it can be said that photons absorbed in the semiconductor create mobile electron-hole pairs, which create a current across the material.

The silicon itself is made up of two parts: a layer of “N” type silicon (“P” for positive), and a layer of “N” type silicon (“N” for negative). N-type silicon has a small amount of material like phosphorous mixed in (“doped”) to provide a prevalence of free electrons. The P-type silicon is doped with a material like boron that has only three electrons in its outer shell instead of four, thus providing an absence of electrons. When these two types of silicon are put together, an electric field is automatically set up. It is this field that allows the electrons to flow from the P side to the N side, which in turn creates a current.

From this slide, you can play an animation that models how silicon-based solar cells work. Click on the image in the slide to launch the animation (requires web access), or go directly to http://nanosense.org/activities/cleanenergy/solarcellanimation.html. You could also preload the animation in your web browser and switch from the slides to the browser to play and talk through the animation. For more information, see [3] and [4].

Also note that this slide relates heavily to the process described in the Solar Cell Teacher Reading, so it would be good to have this on hand as well when presenting these slides. You can decide how much depth you get into with your students. Perhaps you stay at a general level and discuss light being absorbed, exciting electrons, and producing a current. Or you may want to talk in more detail about the two types of silicon layers, the excited electrons and holes, the internal electric field, etc. Again, you can rely just on these notes here or you can bring in greater discussion by having content from the Solar Cell reading at your disposal as well.

Slide 17: Silicon-Based Solar Cell Attributes

Solar cells are expensive to manufacture because of the expense of the single crystal silicon substrates that most solar cells use, and also because they must undergo time-consuming thin film deposition in vacuum chambers.

Long return on investment means that it takes a long time for the device to pay for itself. In this case, it usually takes about 4 years to recoup the cost of manufacturing a conventional solar cell when measured by the amount of energy savings due to collecting the solar energy.

Slide 18: How a Dye-Sensitized Cell Works

In a nanocrystalline cell, titanium dioxide nanoparticles are coated with dye molecules. When sunlight with enough energy hits the dye, electrons are promoted into an excited state and infused into the TiO2 that the dye molecules are attached to. These electrons transfer from the dye via the semiconducting TiO_2 particle layer to the front conductive plate (electrode). At the same time, a positive charge is transferred to the mediator (iodide) and carried to the back plate (the counter electrode). The electrons at the front electrode flow through a wire to a load (e.g. light bulb, motor) and then to the back plate (counter electrode). As the electrons flow to the counter electrode, they encounter the mediator and bring it to its original form, thus completing the electrical circuit.

Note that TiO_2 nanoparticles are used in nano solar cells due to their large surface to volume ratio, their semiconducting properties, and their "invisibleness" to light (i.e. light in the visible range passes right through the TiO2 if it is not absorbed by the dye molecules. The large surface to volume ratio of the TiO_2 helps facilitate the absorption of the dye, which provides a greater number of areas in which a photon can be absorbed by the dye.

From this slide, you can play an animation that models how nanocrystalline solar cells work. Click on the image in the slide to launch the animation (requires web access), or go directly to http://nanosense.org/activities/cleanenergy/solarcellanimation.html. You could also preload the animation in your web browser and switch from the slides to the browser to play and talk through the animation.

Again, the Solar Cell Teacher Reading provides greater depth that you might want to include in your classroom discussing when showing the slides.

Slide 19: Dye Sensitized Solar Cells

This slide highlights particular characteristics of nanocrystalline cell technology; for example, they are relatively inexpensive, flexible, and pay for themselves fairly quickly.

Slide 20: Dye-Sensitized and Silicon-based Solar Cells Compared

This slide revisits the information on the previous 4 slides, comparing and contrasting some characteristics of the two types of solar cells.

Slide 21: Solar Electric Power Plants

This slide highlights large-scale systems. We have already discussed photovoltaic cells as tools to convert sunlight to electricity. Another way to generate electricity is through the more indirect method of using the sun's energy to heat liquid that can, in turn, create steam and drive a turbine/generator system.

You may want to point out to your students that the image at the top is of a solar collection facility owned by PFL Energy, which covers more than 2,000 acres in the California desert. This is currently the largest solar energy generating station in the U.S. The system uses more than 900,000 mirrors that capture and concentrate sunlight. The electricity generated at FPL's Solar Energy Generating Systems (SEGS) could power approximately 230,000 homes. [6]

Slide 22: Solar Heating Systems

Solar heating systems typically consist of a solar thermal collector and a fluid/pump system. In these systems, the fluid is being heated directly by light rays and then pumped into a chamber to heat water. In effect, the system carries heat energy from the sun into a home or other building, allowing for the transfer of heat energy from sun to the household water supply. This is a different process than how solar cells convert sunlight into electricity, which can then be used to power the electrical device of choice.

Slide 23: Wind Energy is Solar Energy

This slide is intended to highlight the fact that wind is created by temperature differences on earth, which is a result of the sun's heat. Wind energy is ample, renewable, widely distributed, clean, and reduces toxic atmospheric and greenhouse gas emissions if used to replace fossil-fuel-derived electricity.

Global Wind Energy Council (GWEC) figures show the 2006 installed wind energy capacity to be 74,223 megawatts [7]. If you figure that a megawatt is enough energy to supply approximately 160 US households, your students can get a sense that in 2006 wind supplied enough energy to power approximately 12 million homes.

Slide 24: Important Summary Questions

This slide revisits some important summary questions that you can use during the class discussion if you like.

References

[1] http://en.wikipedia.org/wiki/Solar_cell

[2] Text and table adapted from http://www.ez2c.de/ml/solar_land_area/

[3] http://www.solarexpert.com/pvbasics2.html

[4] http://en.wikipedia.org/wiki/Solar_panel, http://en.wikipedia.org/wiki/Solar_cell

[5] http://www.terradaily.com/reports/WalMart_To_Go_Solar_To_Save_Energy.html

[6] http://www.fplenergy.com

[7] Global Wind Energy Council (February 2, 2007). Global wind energy markets continue to boom – 2006 another record year (PDF). Press release. Retrieved on 2007-03-11.

Solar Cell Technology: Teacher Reading

Solar Cells Convert Light Energy into Electricity

A solar cell is an *energy conversion device* that converts light energy into electrical energy. Through a multi-step process, a solar cell takes sunlight as an input and generates electrical energy (in the form of a current) as an output. A common misconception is that solar cells produce or create electricity. It is more accurate to say that a solar cell is a device that "converts" light energy from the sun into electrical energy [1][2]. Other examples of energy conversion devices are batteries (conversion of chemical energy to electrical energy), wind and water-powered generators (conversion of mechanical energy to electrical energy), and gasoline engines (conversion of chemical energy to mechanical energy).

A solar cell is an energy conversion device. It converts energy from sunlight into electrical energy.

How Solar Cells Work

Understanding how a solar cell works means understanding the process by which a solar cell converts light into electricity. There are four important steps to the energy conversion process in a solar cell:

1. Sunlight Shines on the Solar Cell
2. Energy is Absorbed to Liberate Electrons
3. Electrons are Transported
4. Circuit is Completed

Below are general explanations of these steps for two specific types of solar cells: newer, nano-influenced dye-sensitized solar cells (Figure 1a), and more traditional, single-crystal silicon solar cells (Figure 1b).

Figure 1a. Dye-sensitized "nano" solar cell [3]

Figure 1b. Single-crystal silicon solar cell [4]

Step 1: Sunlight Shines on the Solar Cell

The solar cell can only absorb energy from the sunlight that shines directly on it. It is also important that the sunlight strikes the solar cell as close to perpendicular as possible, in order to achieve maximum transference light energy to the solar cell. The greater the angle between the sun and the solar cell, the greater the area that the light is spread over. This reduces the energy per unit area. (Note: this angle of incidence phenomenon can be demonstrated in class with a flashlight and beach ball by shining the flashlight onto the ball at different angles and observing the change in area that the light shines on.)

Step 2: Energy is Absorbed to Liberate Electrons

After the light shines on the surface of the solar cell, the light energy needs to be captured by the solar cell so it can be converted into electrical energy. Here the *energy from the light is transferred to electrons* in the material that makes up the solar panel. In both the dye-sensitized solar cells and traditional single-crystal silicon solar cells, there are minimum energies that the light has to have to be able to excite the electrons into a higher energy state.

Dye-Sensitized Solar Cell (DSSC)	Single-Crystal Silicon Solar Cell
In the dye-sensitized solar cell, electrons are liberated from an organic dye material that acts as a "photosensitizer." Ruthenium (Ru) complexes are some of the more promising photosensitizers being used because of their ability to absorb a wide range of visible light (from 400 to 800 or 900 nm [5]). The dye molecules are responsible for absorbing the incident light. However, the light has to have enough energy to promote an electron from an occupied molecular orbital to a higher energy unoccupied molecular orbital. The energy gap of relevance here is that between the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO).	In the single-crystal silicon solar cell, electrons have to have a minimum "band gap" energy before they can be released. Band gap is the energy difference between the top energy level of the valence band and the bottom energy level of the conduction band. The valence band and the conduction band are overlaps of several Si atomic orbitals. For the electrons to jump between the valence band and the conduction band, the valence band has to be partially empty and the conduction band has to be partially full. Electrons can jump from anywhere in the valence band to anywhere in the conduction band, so incident light with an energy equal to or greater than the band gap energy can be used to excite the electrons. In the case of crystalline silicon, the band gap energy of silicon (Si) is about 1.1 eV [6].

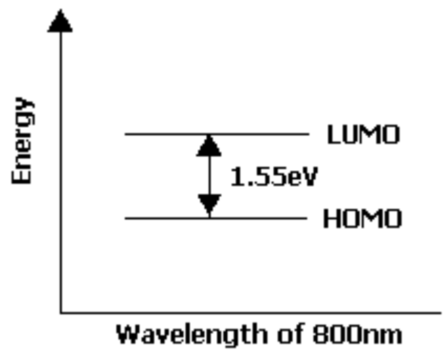


Figure 2. Energy vs. wavelength (800nm)

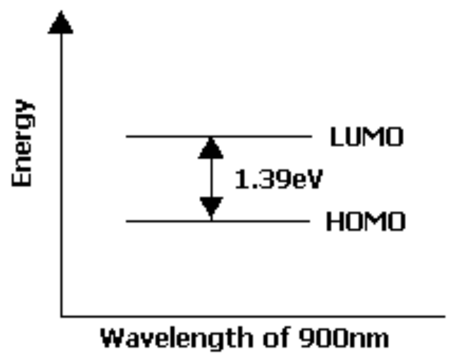


Figure 3. Energy vs. wavelength (900nm)

For typical dyes the energy gap is 1.55eV or 1.38eV (corresponding to 800nm or 900nm, respectively).

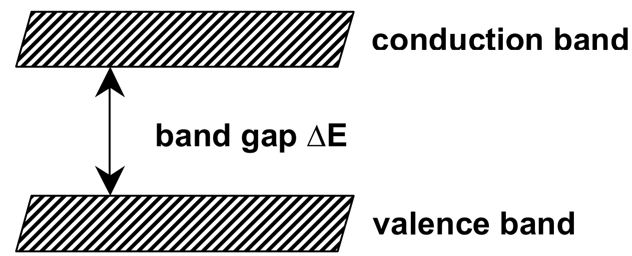
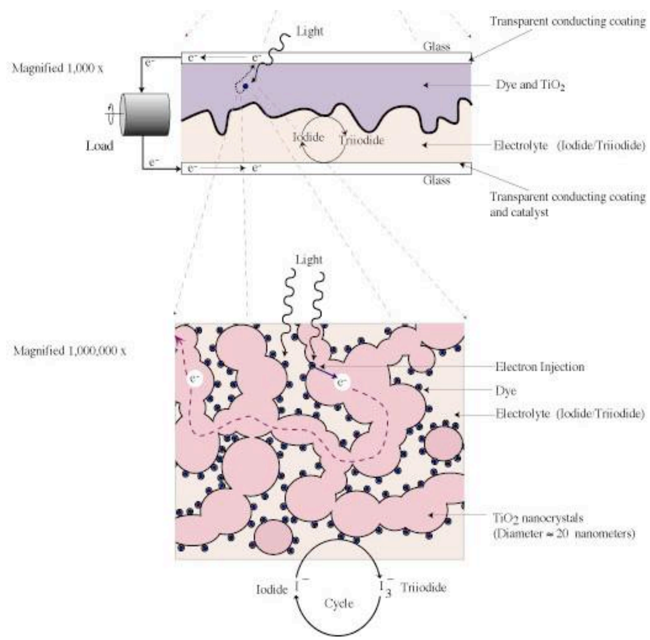
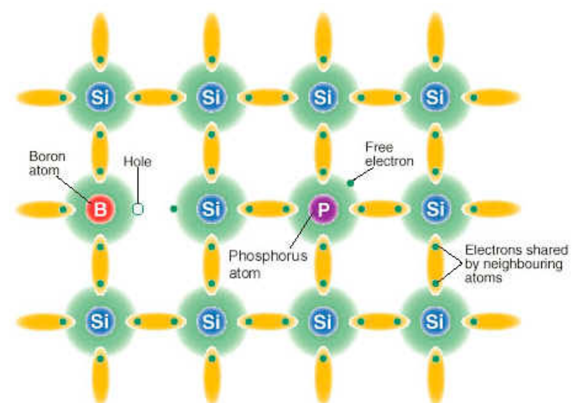


Figure 4. Band gap between conduction band and valence band

Step 3: Electrons are Transported

Now that we have excited electrons, we need a way to "corral" them so they can do work. The goal at this point is to organize the electrons so they form a current, which can be used outside of the cell to drive a motor or light a light bulb.

Dye-Sensitized Solar Cell (DSSC)	Single-Crystal Silicon Solar Cell
In the DSSC, the light-absorbing dye molecules are coated onto very small, dispersed TiO_2 particles. The TiO_2 particles form "layers" that are more spherical than flat (see figures below) –  basically stacks of nano-sized particles covered with dye. *Figure 5. Dye-sensitized solar cell diagrams [7]* The TiO_2 particles range in size from 10nm-30nm, giving them high surface to volume ratios. In the range where the dye molecules convert a significant fraction of incident light into electron energy (400nm-900nm), the TiO_2 is transparent to light. The large surface area of the TiO_2 creates a large surface	In the single-crystal silicon solar cell, crystalline silicon is used. The outer shell of each silicon atom has four electrons, which creates the crystalline structure when the atoms are bonded together—each silicon atom shares an electron on each side with a neighboring silicon atom. Because pure silicon is a poor conductor, other atoms are added ("doped") to the silicon to increase conductivity. By adding phosphorus (P) atoms, an additional electron is added since phosphorus has five electrons in its outer shell. By adding in boron (B) atoms, an empty spot, or "hole" is available (see figure below.)  *Figure 6. "Doped" silicon crystalline lattice [8]* In the single-crystal silicon cell, the added phosphorus and boron atoms are split between two layers. The layer with phosphorus atoms added is called the n-type silicon layer ("n" because of the added negative electrons).

area for absorption for the dye molecules that coat them. Since the TiO_2 is transparent to light in this energy range, light that isn't absorbed by the dye molecules coated onto a particular TiO_2 particle will pass through and be available to be absorbed by the next dye-coated TiO_2 particle that the light strikes.

Figure 5 above shows the construction of a dye-sensitized solar cell. The top figure depicts the dye and TiO_2 situated in the top portion of the cell. The light enters through the top glass plate and excites electrons in the dye. Electrons with enough energy are absorbed into the conduction band of the TiO_2 and are transported to the conductive coating on the top glass plate. The TiO_2 acts as a conduit between the dye molecules (where the electrons originate) and the top contact, and channels the flow of electrons out of the cell. The bottom figure is an expanded view of the dye/ TiO_2 layer. Note that the dye molecules sit on top of the TiO_2 nanocrystals, and that there are various "layers" of the dye/ TiO_2.

Again, since the nano-sized TiO_2 particles do not scatter light in this wavelength range, the light can penetrate into the DSSC and contact multiple layers of dye-coated TiO_2. If the TiO_2 were all larger particles, the light would be scattered out of the cell without penetrating many dye layers, and hence not much of the incident light would be absorbed.

The idea of using nano-sized particles to eliminate scattering is similar in principle to the use of TiO_2 in making "clear" sunscreens. All TiO_2 is good at absorbing UV rays, but thick layers of TiO_2 scatter visible light. Much of this scattered light is reflected back to our eyes, making the sunscreen appear

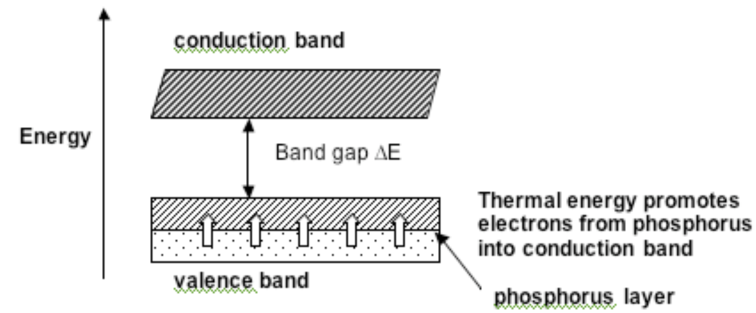


Figure 7. Phosphorus layer in conduction band

The layer with boron atoms added is called the p-type silicon layer ("p" for the added positive holes). It is important to note that the positive holes effectively move around just like the electrons do, so it is safe to think of them as mobile positive charges.

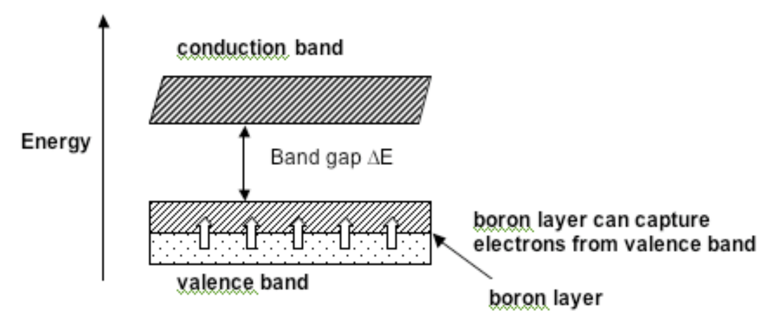


Figure 8. Boron layer in conduction band

When the n-layer and the p-layer are brought into contact with each other, an electric field is set up. This electric field directs the flow of excited electrons that were liberated from the interaction with the sunlight. The

white (because the whole spectrum of visible light together appears white). When nano-sized TiO_2 particles are used instead, absorption of the UV rays still occur, but the smaller particles don't scatter the visible light. The visible light can pass through the TiO_2 particles and reach the skin when the blue/green wavelengths are absorbed and the red/yellow wavelengths are reflected. The person's normal skin color shows through and the sunscreen appears clear.	electric field allows the flow of electrons in one direction only – from the "p" side to the "n" side. As such, when the sunlight strikes the solar cell, electron-hole pairs are freed, and, due to the electric field, they are separated. It is this separation (and ultimately the recombination) of electron-hole pairs that generates a current.

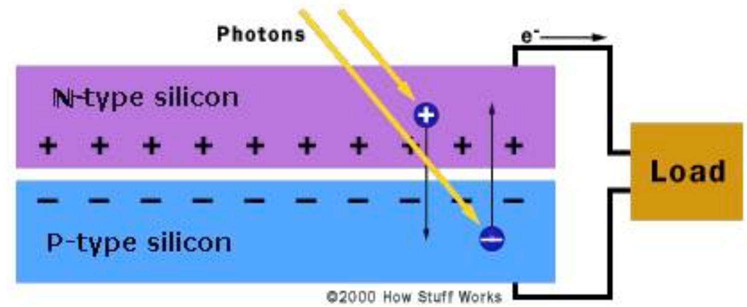


Figure 9. Silicon solar cell schematic [9]

Step 4: Circuit is Completed

For the excited electrons to actually move in a controlled fashion and do work, there needs to be a complete path for their flow.

Dye-Sensitized Solar Cell (DSSC)	Single-Crystal Silicon Solar Cell
In the dye-sensitized solar cell, the flow of excited electrons from the dye molecules into the TiO_2, and then through the TiO_2 to the top conducting plate of the cell, sets up a potential difference (i.e. voltage). Once the electrons re-enter the solar cell they need a way to move from the bottom contact back up to the TiO_2 and dye molecules at the top. An ionic iodide solution is used to make this "last mile" happen – the solution acts as a transportation path for moving the electrons back to where they started. Once the electrons reach the dye, they fill in the positive holes that were created when they left. Again, it is	In the silicon solar cell, to make the electrons move the electric field set up within the silicon creates a potential difference (a "voltage") between where the electrons leave the solar cell and where they re-enter the solar cell. This voltage can be thought of as acting like a pump, pushing the electrons out the top of the solar cell and back to the bottom of the solar cell.

the charge separation—the excess negative charge from the electrons moving out of the top of the solar cell, and the positive holes left behind—that sets up the potential difference in the cell and influences the electrons to move in the completed circuit.	

A Note on Efficiency

In general, silicon-based solar cells tend to be more efficient at generating electricity from light energy than dye-sensitized solar cells. However, it is important to note that dye-sensitized solar cells (DSSCs) have several advantages over silicon-based solar cells. First, DSSCs are more effective at picking up light earlier in the morning and later in the evening. This allows the DSSCs to operate for a longer portion of the day than silicon-based solar cells. Second, DSSCs are less affected by temperature—they can operate as efficiently in hot climates at they can in cold [10]. Standard silicon-based solar cells are more sensitive to temperature, with their efficiency dropping under particularly hot and cold conditions. Given these two advantages, when real-life operation is considered, the overall efficiency of DSSCs comes close to that of silicon-based solar cells. DSSCs tend to be about 10% efficient [11], with silicon-based solar cells being slightly more efficient (approximately 12%-15% efficient.)

In Summary

These are the four basic steps of the process in a solar cell. Even though single-crystal silicon and dye-sensitized solar cells differ in the materials they are made of, there are many similarities in the energy conversion process between the two. One final similarity is that in both cases optimization is important in each part of the system, so as to increase the efficiency of the solar cell. By improving the efficiency of the various components, the overall efficiency of the solar cell improves [12].

References

[1] See http://www.howstuffworks.com/light1.htm for a general description of the dual nature of light.

[2] For a more detailed description of light see http://en.wikipedia.org/wiki/Light#Particle_theory

[3] Source: http://www.elp.uji.es/juan_home/images/solar_cell/flex1.JPG

[4] Source: http://www.wisconsun.org/images/siemen_cell.jpg

[5] Hara, K., and Arakawa, H. (2003). Dye-sensitized solar cells. In the Handbook of Photovoltaic Science and Technology, Luque, A., and Hegedus, S. (Eds.) John Wiley and Sons. Hoboken, N.J.

[6] For a more detailed discussion on band gap and energy losses in solar cells, see http://science.howstuffworks.com/solar-cell4.htm

[7] Source: http://www.solideas.com/images/diagram.jpg

[8] Source: http://www.corrosion-doctors.org/Solar/images/silicon.jpg

[9] Source: http://science.howstuffworks.com/solar-cell3.htm

[10] See www.technologyreview.com/Energy/17490/. Retrieved 10-02-07.

[11] Dye Sensitized Solar Cells (DYSC) based on Nanocrystalline Oxide Semiconductor Films. Laboratory for Photonics and Interfaces, Swiss Federal Institute of Technology, CH-1015 Lausanne, Switzerland. Printed from lpi.epfl.ch/solarcellE.html on 05-16-07.

[12] For an even more detailed description of the full process of how a solar cell works, a good description is provided at http://science.howstuffworks.com/solar-cell.htm

Silicon and Nanocrystalline Solar Cell Animations: Teacher Instructions & Answer Key

This animation worksheet is best used as an in class activity with small groups in order to give students a chance to discuss the different things they notice in the animations. If you have a limited amount of in-class time you may want to do it as a whole class activity with a follow-up class discussion.

Important: These models are meant to provoke questions and start a discussion about how different types of solar cells work as well as about the process of making decisions about how to represent things in models. They are not perfect and are not meant to be shown to students simply as an example of "what happens".

Introduction

Every day, the amount of "solar energy" (energy from the sun) hitting the Earth is enough to satisfy the annual energy needs of our *whole planet* many times over. Although the direct application of solar energy is helpful for things like heating water or drying clothes, we can gain considerably more benefit by converting solar energy into other forms of energy that we can use.

One very helpful conversion is from solar energy into electrical energy. A device that can do this conversion is called a solar cell. In this activity you will view an interactive animation that shows how two types of solar cells work—both nano-based, dye-sensitized solar cells and single-crystal silicon solar cells—and how they provide electricity for powering a device (in this case a light bulb).

Open the animation file as instructed by your teacher and explore the animations using different solar cell types and light intensities. After you've explored the animations a bit, work through the questions below.

Viewing the Animations Online:
To view the animations, have your students navigate to the Clean Energy Materials web page at http://nanosense.org/activities/cleanenergy/solarcellanimation.html.

Downloading the Animations:
If you have a slow Internet connection or want to have a copy of the animation on your computers for offline viewing, follow the directions at http://nanosense.org/activities/cleanenergy/solarcellanimation.swf to download the file. To view the animation, simply open the file "solarcellanimation.swf" in your web browser.

Questions

1. What are two similarities between the animations? Focus on similarities that do something (e.g. how a part of the animation works) rather than simply descriptions (e.g. the color of a particular part).

> Look for student responses that point out functional similarities such as:
>
> - Light energy (photons) interact with a material to release electrons
> - The solar cell and light bulb combination is a complete circuit, so a current can flow and the process can continue.
> - After the electrons pass through the light bulb, they go back up to where they generally started to "neutralize" the material. In other words, the electrons fill in the "holes" (valence shell) they left behind.
> - Conducting plates and wires are used to help transport the electrons.

2. What are two differences between the animations? Again, choose functional differences rather than labels.

> Some differences here include:
>
> - The nanocrystalline animation has an iodide solution in it that helps the electrons flow back to where they started; the silicon solar cell doesn't have this.
> - In the nanocrystalline solar cell, the electrons originate from the dye molecules, whereas in the silicon solar cell the electrons originate in the "positive layer" part of the silicon.
> - In the silicon solar cell, visible "holes" are left behind after the electron leaves – this hole is filled back in by an electron after the electron goes through the light bulb. In the nanocrystalline solar cell, the "hole" is in the dye molecule, but it is not represented in the animation.

3. What happens in the solar cells as you increase the light intensity? Why do you think this happens?

> Increased light intensity means that more photons hits the solar cell each second. This means the overall amount of energy captured from the light is increased. This translates into greater electron flow (greater current).

4. What is the function of the **conducting plates** in the solar cells?

> The conducting plates "collect" electrons flowing out of the solar cell and direct them into the wire. They also help direct electrons from the wire back into the solar cell.

5. In the dye-sensitized solar cell, what function does the **iodide solution** serve?

The iodide solution helps complete the circuit by transporting the electrons back to where they started – the dye molecules. In the dye-sensitized solar cell there is a gap between the incoming conducting plate (the plate on the bottom), and the dye molecule/TiO_2 layer – the iodide solution provides a way for the electrons to flow back to the dye molecules.

6. The four parts to this question all refer to the dye-sensitized solar cell animation.

   a. Where do the electrons start their journey?

In the dye molecules.

   b. What is the function of the **titanium dioxide** (TiO_2)?

To carry the electrons from the dye molecules to the top conducting plate.

   c. Where do they end their journey?

Back in a dye molecule – they basically start and end their journey in the same place.

   d. Why do you think the electrons follow the journey that they do?

This question is a bit open ended, but in general look for student responses that highlight the idea of electrons "completing a circuit": electrons flowing out of the solar cell through the conducting plate/wire, though the light bulb, back into the solar cell via the wire/conducting plate, then through the iodide solution and back to a dye molecule. There is a charge imbalance set up in the solar cell when the electrons leave – there is a net positive charge that needs to be filled back in with negative charge.

7. What is the effect on the solar cell if a cloud passes in front of the sun?

The cloud reduces the intensity of the sunlight – reduces the number of photons hitting the solar cell per second. This means that the solar cell will generate a lower electrical output.

Nanocrystalline Solar Cell Lab Activity: Teacher Instructions & Answer Key

Nanocrystalline solar cells provide a flexible and relatively inexpensive alternative to traditional silicon-based solar cells. Whereas the manufacturing of traditional solar cells is a time-consuming process that involves expensive equipment, the manufacturing of nanocrystalline solar cells is a simpler process that you can actually do in your classroom.

In this lab activity your students will build a nanocrystalline solar cell and use it to generate electricity. Students should work in groups on this lab.

Overview

This laboratory procedure will demonstrate the operating principles of the nanocrystalline solar cell and those of photosynthesis. The objectives of the experiment over the next two days are to:

- Deposit the TiO_2 nanocrystalline ceramic film on conductive glass.
- Extract a natural dye.
- Determine how the physical and electronic coupling of an organic compound to an oxide semiconductor can occur via **complexation** and **chelation.**
- Determine the characteristics of the assembled photoelectrochemocal cell and to compare this output to the chemical processes occurring in photosynthesis found in green plants.

The materials for this lab are contained in a kit that is available through the Institute for Chemical Education. The kit, "Nanocrystalline Solar Cell Kit–Recreating Photosynthesis," contains both materials and instructions to build a set of solar cells in your classroom [1]. Information how to order the kit can be found at http://ice.chem.wisc.edu/catalogitems/ScienceKits.htm#SolarCell

This lab activity is typically a two-day process. If you have two days of classroom time, you can follow the instructions contained in the kit itself. If you only have one class period (50 minutes) to devote to this lab, you can prepare some of the materials ahead of time (e.g., doing some of the tasks that the students would typically do on the first day).

Regarding procedure, you have two options. One option is to follow the **instructions contained in the kit itself**. This procedure is very thorough, but may be best suited for more advanced students (e.g., students with a few years of science background).

Alternately, you can follow the **instructions below**, a somewhat simplified version of the procedure in the kit. The procedure below is intended for more novice students (e.g., introductory science students).

In either case, if you are interested in making this a one-day lab, simply prepare the day-one materials (e.g., TiO_2 suspension, deposition of the TiO_2 film) ahead of time and then have your students follow the day-two procedure in class.

Caution

Throughout both days of the lab, **do not touch the face of the glass plates**. Oils from fingers will contaminate the surfaces, and could cause your solar cell to fail. Hold the glass plates with tweezers or by the edges of the glass.

Materials: Day One

In your kit:

- Goggles
- 2 conductive, tin dioxide-coated transparent glass plates
- Tweezers
- Glass stirring rod
- Chem Wipe tissues
- Ethanol dropper
- Portable flame burner
- Ring stand
- Ceramic triangle
- Petri dish
- Ziploc bag
- Timer

Teacher has:

- Multimeter
- Transparent tape
- TiO_2 suspension
- Permanent marker

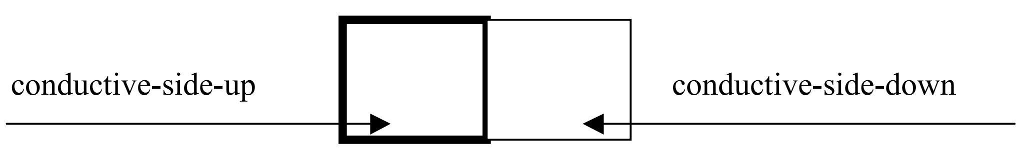
Procedure: Day One

Groups will be assigned, and each person in the group will be responsible for specific procedures. **The group must work together to do all procedures in order.**

1. Clean both glass plates by rinsing them with a couple drops of ethanol and drying with a chem wipe.

2. **a**. Use a multimeter set to ohms to determine conductive side of each plate. The reading should be between 10 and 30 ohms.

   b. Place plates on the tabletop with one conductive-side-up and one conductive-side-down. Mark which one is conductive-side-up so your partners can see it and set both right next to each other as in the figure below.



3. **a**. Get three strips of transparent tape (2 pieces 7 cm long, 1 piece 5cm long).

   b. Tape the plates in place on the tabletop so you have a taped edge NOT MORE THAN 1mm wide on the LONGER EDGES. Place the shorter piece of tape across the top of the conductive-side-up plate, overlapping the tape 4-5 mm along the top edge.

4. **a**. Get drops of TiO_2 from the teacher.

   b. Quickly smear the conductive-side-up plate with TiO_2 by sliding a horizontal glass rod across the TiO_2 drops. Slide the rod back and forth the 2-3 times WITHOUT LIFTING IT OFF THE PLATE. If the TiO_2 coating looks uneven, or if it doesn't cover the whole conductive plate, undo the setup and clean both plates again with ethanol and start again.
5. Set up the ringstand, triangle, and burner.
6. Adjust the ringstand so that it is positioned right at the tip of the burner flame.
7. Remove the tape. Using the timer, let the conductive plate dry off for 1 minute.
8. Pick up the non-coated plate and wash it off.
9. Test the ringstand set up for size and distance from flame using the non-coated plate.
10. Place the coated conductive plate on the triangle with the coated side facing up.
11. Light the burner separate from the ringstand setup, and then move it under the ring and plate.
12. Start the timer and watch the setup for 10-15 minutes. On the next page, record what happens to your coated plate over the 10-15 minutes it is above the flame.
13. Use a permanent marker to write all group member names on the ziplock bag.
14. After 10-15 minutes, extinguish the flame.
15. Make sure nobody touches or moves the hot glass plate! Start the timer and let the plate cool for 10-15 minutes.
16. While you are waiting for the hot glass plate to cool, put the (cool) non-coated plate in the ziplock bag.
17. After 10-15 minutes of cooling, carefully place the coated plate in the ziplock bag.

Observations

Describe what happens to your coated plate over the 10-15 minutes it is above the flame.

After applying the TiO_2 drops, which was kind of a pasty white material, and then letting it sit over the flame for 15 minutes, it slowly "baked" onto the slide, forming a somewhat clear coating so you could actually see though the slide.

Look for students to note any qualitative changes in the TiO_2 during/after heating.

Record any other changes your group made to the procedure. Did every step go smoothly? Why or why not?

Possible student responses include: changes to the process of spreading TiO_2 on the slide, notes on how/why they tested the ringstand size/distance from flame, and any mistakes/restarts. Look for student engagement with the lab procedure and willingness to modify it as needed.

Questions

1. What is (define) a semiconductor?

Semiconductors are solid materials with a level of electrical conductivity between that of insulators and conductors. They are used in computer chips and solar cells because of their ability to control electrical currents.

Look for whether students mention both insulation and conduction related properties AND that semiconductors are used extensively in electronic type devices due to their ability to control the flow of electrons through them.

2. What is the semiconductor in the nanocrystalline solar cell?

Titanium dioxide is a semiconductor, which enables the electrons to move away (conduct) from the dye molecules and into the circuit. Once the electrons move through the load (like a light bulb, motor, or multimeter) and to the bottom conductive plate, an iodide solution carries the electrons back to the dye molecules.

Materials: Day Two

In your kit:

- Goggles
- YOUR 2 conductive, tin dioxide-coated transparent glass plates. One is already coated with TiO_2 and the other is clean.
- Tweezers
- Chem. Wipe tissues
- Ethanol dropper
- Deionized water dropper
- Petri dish
- Q-tips
- (2) Binder clips
- (2) Different-colored sets of alligator clips

Teacher has:

- Multimeter
- Graphite pencil (carbon catalyst)
- TiO_2 suspension
- Iodide dropper
- Test loads

Procedure: Day Two

Groups will be assigned, and each person in the group will be responsible for specific procedures. **The group must work together to do all procedures in order.**

1. Obtain a few drops of anthocyanin (from blackberries) dye from the teacher. Place enough dye in the Petri dish to cover the entire bottom of your coated glass plate.
2. Place the TiO_2 coated plate (the electrode) in the Petri dish so that the coated side is facing down and sitting in dye.
3. Begin timing 10 minutes. The plate must remain in the dye for 10 minutes.
4. While the coated plate is soaking, prepare the uncoated plate by washing it with ethanol.
5. Use the multimeter to determine the conductive side of the uncoated plate.
6. Use the special graphite pencil provided to apply a light carbon film to THE ENTIRE CONDUCTIVE SIDE of the plate by rubbing the pencil *gently* over the entire surface. Set this plate aside.
7. Once the TiO_2 plate (the electrode) has soaked for 10 minutes, carefully lift it out of the Petri dish.
8. Rinse the plate with a couple of drops of deionized water, then with a couple of drops of ethanol.
9. Once the electrode plate is completely dry, place it on the tabletop so that the TiO_2 surface is facing up.
10. Carefully place the carbon-coated plate (the counter electrode) on top of the TiO_2 plate (the electrode) so that the conductive side (pencil-covered side) faces the TiO_2 film.
11. *Gently* place the to electrodes so that they DO NOT line up exactly! All of the TiO_2 should be covered by the top plate, but the thickest uncoated edge (made yesterday with tape) is exposed or hanging over.

12. Once in this proper position, *carefully* pick up the assembly and place the two binder clips on the **longer** edges to hold the plates together.
13. Obtain a few drops of iodide (electrolyte) from the teacher. The iodide (electrolyte) should be placed at one overlapping edge, allowing it to be drawn between the plates by capillary action. Make sure the entire stained portion of the plate is covered with iodide (electrolyte).
14. Use tissue or Q-tip to wipe off any excess iodide (electrolyte) that remains on the outside of the assembly.
15. YOU'RE READY TO TEST YOUR SOLAR CELL!

    The solar cell can be hooked up to the multimeter or a device needing power by attaching the alligator clips. The negative electrode is the plate coated with TiO_2, and should be attached to the black (-) wire. The counter electrode is (+) and should be connected to the red wire. Complete the observation questions below.

Observations

1. Connect one solar cell directly to the multimeter. What is the maximum voltage (volts) across the solar cell, as measured by the multimeter?	Will depend on individual cell	volts
2. What is the maximum current in milliamps (mA) through one solar cell, as measured by the multimeter?	Will depend on individual cell	mA
3. Connect two cells in a series. What is the voltage of two cells connected in series?	Roughly 2 times the voltage in #1	volts
4. What is the current through two cells connected in series?	Roughly 2 times the current in #2	mA

5 What loads did you attempt to run using your solar cell as the power source?

Loads here refer to any external device the student tried to power using the solar cell. Some possible responses include a light bulb, a small motor, and the multimeter (small load to detect current/voltage).

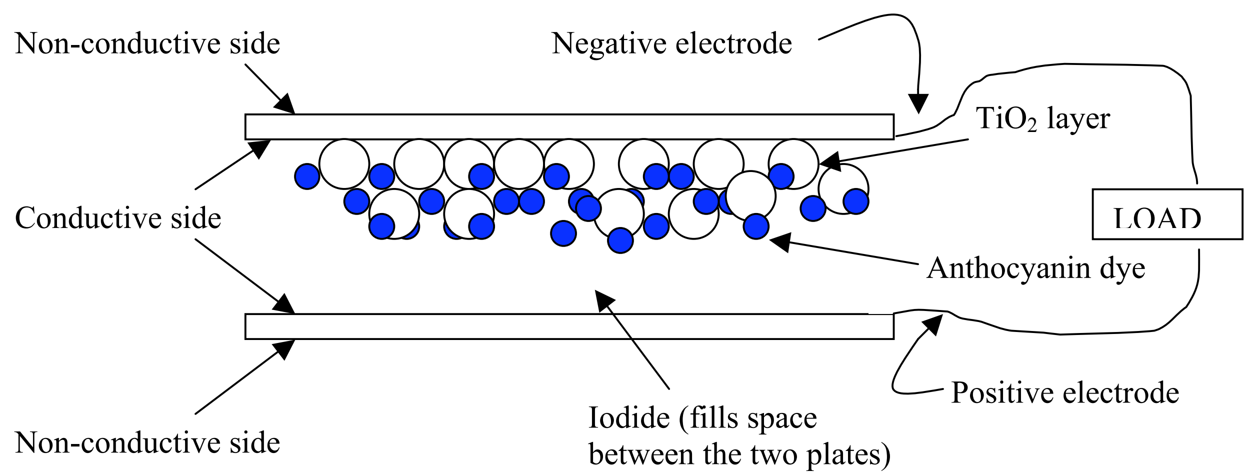
6. Which loads were run successfully using your solar cell as the power source?

Look for list of lower amperage devices since the cell generates a very small current. This list will depend on the devices provided to the student by the teacher for the lab since the kit itself doesn't include any devices.

Analysis

1. Create a sketch of your solar cell in the box below. Include labels for the following:

- Conductive sides of the plates
- Non-conductive sides of the plates
- TiO_2 layer
- Anthocyanin dye
- Iodide
- Positive
- Negative electrode
- Positive electrode



2. Write a few lines about what you learned and the relationship between photosynthesis and solar energy.

In the nanocrystalline solar cell, the process of converting sunlight into electricity is similar to the process of photosynthesis in that they both use light as input and convert it into another form of energy. In photosynthesis, light energy is used to ultimately make glucose, but it does generate a flow of electrons (basically electricity) down an electron transport chain. Both the nanocrystalline solar cell and photosynthesis rely on organic materials to absorb photons and release electrons: in the nanocrystalline cell it is the anthocyanin dye; in photosynthesis it is the pigment chlorophyll.

Check to see if the student points out that in photosynthesis, sunlight is converted to electricity in part of the process, and that an organic material – chlorophyll – is the key ingredient that absorbs photons and releases electrons.

3. What parts (if any) of the procedures from day one or day two were difficult to understand or complete? Explain why you felt it was difficult and what (if anything) could have made it easier.

Look for any responses related to the procedure and/or concepts from either day. Since making the actual nanocrystalline cell is a detailed and fairly precise process, student may have found that parts of the creation of the cell were difficult and may have had to repeat part of the process. For each statement about difficulties, look for a statement on how to make things easier.

References

[1] http://ice.chem.wisc.edu/catalogitems/ScienceKits.htm#SolarCell

Name__________________________________ Date______________________ Period ______

Reflecting on the Guiding Questions: Teacher Instructions

The following questions focus on some of the main science ideas of the unit. This worksheet is intended as a formative assessment before students begin the nanocrystalline lab for you and your students to get a sense of understanding of the content of the unit.

Think about the activity you just completed. What did you learn that will help you answer the guiding questions? Jot down notes in the spaces below.

1. What are some current energy issues facing the world today?

What I learned in this activity:

What I still want to know:

2. What are alternative, clean energy sources? How might they help our energy issues?

What I learned in this activity:

What I still want to know:

3. How do silicon-based solar cells work? How do nanocrystalline solar cells work?

What I learned in this activity:

What I still want to know:

Lesson 2:
Solar Energy and Nanoscience

Student Materials

Contents

Name____________________________________ Date_______________________ Period ______

Silicon and Nanocrystalline Solar Cell Animations: Student Instructions

Introduction

Every day, the amount of "solar energy" (energy from the sun) hitting the Earth is enough to satisfy the annual energy needs of our *whole planet* many times over. Although the direct application of solar energy is helpful for things like heating water or drying clothes, we can gain considerably more benefit by converting solar energy into other forms of energy that we can use.

One very helpful conversion is from solar energy into electrical energy. A device that can do this conversion is called a solar cell. In this activity you will view an interactive animation that shows how two types of solar cells work—both nano-based, dye-sensitized solar cells and single-crystal silicon solar cells—and how they provide electricity for powering a device (in this case a light bulb).

Open the animation file as instructed by your teacher and explore the animations using different solar cell types and light intensities. After you've explored the animations a bit, work through the questions below.

Viewing the Animations Online:
To view the animations, have your students navigate to the Clean Energy Materials web page at http://nanosense.org/activities/cleanenergy/solarcellanimation.html.

Downloading the Animations:
If you have a slow Internet connection or want to have a copy of the animation on your computers for offline viewing, follow the directions at http://nanosense.org/activities/cleanenergy/solarcellanimation.swf to download the file. To view the animation, simply open the file "solarcellanimation.swf" in your web browser.

Questions

1. What are two similarities between the animations? Focus on similarities that do something (e.g. how a part of the animation works) rather than simply descriptions (e.g. the color of a particular part).

2. What are two differences between the animations? Again, choose functional differences rather than labels.

3. What happens in the solar cells as you increase the light intensity? Why do you think this happens?

4. What is the function of the **conducting plates** in the solar cells?

5. In the dye-sensitized solar cell, what function does the **iodide solution** serve?

6. The four parts to this question all refer to the dye-sensitized solar cell animation.

a. Where do the electrons start their journey?

b. What is the function of the **titanium dioxide** (TiO_2)?

c. Where do they end their journey?

d. Why do you think the electrons follow the journey that they do?

7. What is the effect on the solar cell if a cloud passes in front of the sun?

Name________________________________ Date_____________________ Period ______

Nanocrystalline Solar Cell Lab Activity: Student Instructions & Worksheet

Overview

This laboratory procedure will demonstrate the operating principles of the nanocrystalline solar cell and those of photosynthesis. The objectives of the experiment over the next two days are to:

- Deposit the TiO_2 nanocrystalline ceramic film on conductive glass.
- Extract a natural dye.
- Determine how the physical and electronic coupling of an organic compound to an oxide semiconductor can occur via **complexation** and **chelation.**
- Determine the characteristics of the assembled photoelectrochemocal cell and to compare this output to the chemical processes occurring in photosynthesis found in green plants.

Caution

Throughout both days of the lab, **do not touch the face of the glass plates**. Oils from fingers will contaminate the surfaces, and could cause your solar cell to fail. Hold the glass plates with tweezers or by the edges of the glass.

Materials: Day One

In your kit:

- Goggles
- 2 conductive, tin dioxide-coated transparent glass plates
- Tweezers
- Glass stirring rod
- Chem Wipe tissues
- Ethanol dropper
- Portable flame burner
- Ring stand
- Ceramic triangle
- Petri dish
- Ziploc bag
- Timer

Teacher has:

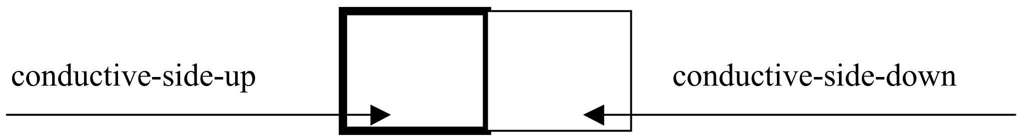
- Multimeter
- Transparent tape
- TiO_2 suspension
- Permanent marker

Procedure: Day One

Groups will be assigned, and each person in the group will be responsible for specific procedures. **The group must work together to do all procedures in order.**

1. Clean both glass plates by rinsing them with a couple drops of ethanol and drying with a chem wipe.
2. **a**. Use a multimeter set to ohms to determine conductive side of each plate. The reading should be between 10 and 30 ohms.

   b. Place plates on the tabletop with one conductive-side-up and one conductive-side-down. Mark which one is conductive-side-up so your partners can see it and set both right next to each other as in the figure below.



3. **a**. Get three strips of transparent tape (2 pieces 7 cm long, 1 piece 5cm long).

   b. Tape the plates in place on the tabletop so you have a taped edge NOT MORE THAN 1mm wide on the LONGER EDGES. Place the shorter piece of tape across the top of the conductive-side-up plate, overlapping the tape 4-5 mm along the top edge.
4. **a**. Get drops of TiO_2 from the teacher.

   b. Quickly smear the conductive-side-up plate with TiO_2 by sliding a horizontal glass rod across the TiO_2 drops. Slide the rod back and forth the 2-3 times WITHOUT LIFTING IT OFF THE PLATE. If the TiO_2 coating looks uneven, or if it doesn't cover the whole conductive plate, undo the setup and clean both plates again with ethanol and start again.
5. Set up the ringstand, triangle, and burner.
6. Adjust the ringstand so that it is positioned right at the tip of the burner flame.
7. Remove the tape. Using the timer, let the conductive plate dry off for 1 minute.
8. Pick up the non-coated plate and wash it off.
9. Test the ringstand set up for size and distance from flame using the non-coated plate.
10. Place the coated conductive plate on the triangle with the coated side facing up.
11. Light the burner separate from the ringstand setup, and then move it under the ring and plate.
12. Start the timer and watch the setup for 10-15 minutes. On the next page, record what happens to your coated plate over the 10-15 minutes it is above the flame.
13. Use a permanent marker to write all group member names on the ziplock bag.
14. After 10-15 minutes, extinguish the flame.
15. Make sure nobody touches or moves the hot glass plate! Start the timer and let the plate cool for 10-15 minutes.

16. While you are waiting for the hot glass plate to cool, put the (cool) non-coated plate in the ziplock bag.

17. After 10-15 minutes of cooling, carefully place the coated plate in the ziplock bag.

Observations

Describe what happens to your coated plate over the 10-15 minutes it is above the flame.

Record any other changes your group made to the procedure. Did every step go smoothly? Why or why not?

Questions

1. What is (define) a semiconductor?

2. What is the semiconductor in the nanocrystalline solar cell?

Materials: Day Two

In your kit:

- Goggles
- YOUR 2 conductive, tin dioxide-coated transparent glass plates. One is already coated with TiO_2 and the other is clean.
- Tweezers
- Chem. Wipe tissues
- Ethanol dropper
- Deionized water dropper
- Petri dish
- Q-tips
- (2) Binder clips
- (2) Different-colored sets of alligator clips

Teacher has:

- Multimeter
- Graphite pencil (carbon catalyst)
- TiO_2 suspension
- Iodide dropper
- Test loads

Procedure: Day Two

Groups will be assigned, and each person in the group will be responsible for specific procedures. **The group must work together to do all procedures in order.**

1. Obtain a few drops of anthocyanin (from blackberries) dye from the teacher. Place enough dye in the Petri dish to cover the entire bottom of your coated glass plate.
2. Place the TiO_2 coated plate (the electrode) in the Petri dish so that the coated side is facing down and sitting in dye.
3. Begin timing 10 minutes. The plate must remain in the dye for 10 minutes.
4. While the coated plate is soaking, prepare the uncoated plate by washing it with ethanol.
5. Use the multimeter to determine the conductive side of the uncoated plate.
6. Use the special graphite pencil provided to apply a light carbon film to THE ENTIRE CONDUCTIVE SIDE of the plate by rubbing the pencil *gently* over the entire surface. Set this plate aside.
7. Once the TiO_2 plate (the electrode) has soaked for 10 minutes, carefully lift it out of the Petri dish.
8. Rinse the plate with a couple of drops of deionized water, then with a couple of drops of ethanol.
9. Once the electrode plate is completely dry, place it on the tabletop so that the TiO_2 surface is facing up.
10. Carefully place the carbon-coated plate (the counter electrode) on top of the TiO_2 plate (the electrode) so that the conductive side (pencil-covered side) faces the TiO_2 film.
11. *Gently* place the to electrodes so that they DO NOT line up exactly! All of the TiO_2 should be covered by the top plate, but the thickest uncoated edge (made yesterday with tape) is exposed or hanging over.

12. Once in this proper position, *carefully* pick up the assembly and place the two binder clips on the **longer** edges to hold the plates together.
13. Obtain a few drops of iodide (electrolyte) from the teacher. The iodide (electrolyte) should be placed at one overlapping edge, allowing it to be drawn between the plates by capillary action. Make sure the entire stained portion of the plate is covered with iodide (electrolyte).
14. Use tissue or Q-tip to wipe off any excess iodide (electrolyte) that remains on the outside of the assembly.
15. YOU'RE READY TO TEST YOUR SOLAR CELL!

    The solar cell can be hooked up to the multimeter or a device needing power by attaching the alligator clips. The negative electrode is the plate coated with TiO_2, and should be attached to the black (-) wire. The counter electrode is (+) and should be connected to the red wire. Complete the observation questions below.

Observations

1. Connect one solar cell directly to the multimeter. What is the maximum voltage (volts) across the solar cell, as measured by the multimeter? ______ volts

2. What is the maximum current in milliamps (mA) through one solar cell, as measured by the multimeter? ______ mA

3. Connect two cells in a series. What is the voltage of two cells connected in series? ______ volts

4. What is the current through two cells connected in series? ______ mA

5 What loads did you attempt to run using your solar cell as the power source?

6. Which loads were run successfully using your solar cell as the power source?

Analysis

1. Create a sketch of your solar cell in the box below. Include labels for the following:

- Conductive sides of the plates
- Non-conductive sides of the plates
- TiO_2 layer
- Anthocyanin dye
- Iodide
- Positive
- Negative electrode
- Positive electrode

2. Write a few lines about what you learned and the relationship between photosynthesis and solar energy.

3. What parts (if any) of the procedures from day one or day two were difficult to understand or complete? Explain why you felt it was difficult and what (if anything) could have made it easier.

Name________________________________ Date_____________________ Period ______

Reflecting on the Guiding Questions: Student Worksheet

Think about the activity you just completed. What did you learn that will help you answer the guiding questions? Jot down notes in the spaces below.

1. What are some current energy issues facing the world today?

What I learned in this activity: What I still want to know:

2. What are alternative, clean energy sources? How might they help our energy issues?

What I learned in this activity: What I still want to know:

3. How do silicon-based solar cells work? How do nanocrystalline solar cells work?

What I learned in this activity: What I still want to know: