ENERGY 101

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Science, Technology, and Society

A peer reviewed curricular framework for an interdisciplinary higher education undergraduate course for teaching the fundamentals of energy using a systems-based approach

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SCIENCE, TECHNOLOGY AND SOCIETY

BACKGROUND

In cooperation with the U.S. Department of Energy (DOE), APLU and its partners have spent nearly a year developing the following one-semester “Introduction to Energy” (Energy 101) Model Curriculum for colleges, universities, and community colleges.

The project builds on two years of prior DOE-led work to reach a consensus on what every citizen should know about energy. DOE’s energy literacy effort began at a workshop sponsored by DOE and the American Association for the Advancement of Science (AAAS) in the Fall of 2010, and concluded with the publication of *Energy Literacy: Essential Principles and Fundamental Concepts for Energy Education* (Energy Literacy Principles) last year after thousands of individuals and many organizations and federal agencies had shared their expertise. The Energy 101 effort has taken this work a step further by studying existing college-level introductory energy courses, by developing research and evaluation protocols for Energy 101, by thinking through how technology and DOE’s National Training & Education Resource (NTER) can be used for Energy 101, by developing related courses and instructional materials, and by focusing on other standardization issues like transferability of credit if the Model Curriculum is to be readily usable for AP, community college, and university courses. NTER is an open-source educational tool that provides course developers and users with free access to advanced information technology and graphics capability. NTER is available on a cloud-based platform that facilitates the sharing of module content and interactive communications.

The Energy 101 project team began its efforts by mapping the energy literacy principles against “introduction to energy” curricula from 16 universities and community colleges. Through these exercises, the team identified the Energy Literacy Principles that repeatedly appear in courses and those that are either too specialized or too advanced for a freshman-level introductory course. The results were organized into the first of several drafts of the Model Curriculum and circulated widely throughout the university and energy policy communities. Numerous improvements have been made based on the comments received. This final draft was circulated through the membership of additional educational associations and a small group of senior energy-expert reviewers and this final version reflects their ideas as well.

The approach of former Carnegie Mellon University Vice Provost of Education Indira Nair’s *Introduction to Environmental Science* course inspired and informed the design of Energy 101. Dr. Nair’s course, which she taught for a decade at Carnegie Mellon, attracted students from numerous majors across the university who worked in teams and were encouraged to think about problems and solutions holistically, drawing on their collective knowledge bases. Energy and environment are similarly broad, multi-disciplinary topics. Accordingly, courses based on this Model Curriculum should include a broad survey of energy and related fields and culminate with group projects that can be chosen with student input, that pull together what students have learned about energy, that draw on the individual students’ majors, and that are set within the context of the students’ school, their community, or a broader area. Even though the Model Curriculum is presented in the same order as the Energy Literacy Principles, professors may choose a different presentation order of the subject matter. Some professors, for example, may wish to begin with actual applications; others may wish to teach the course as it is laid out and begin with the science of energy.

Since both the Energy Literacy Principles and the Model Curriculum are focused on energy literate decision making, the Model Curriculum goes beyond knowledge of energy systems, physical energy processes, biological energy processes, and energy transfer to proper understanding and application of the economic, ethical, societal, and international factors that guide energy choices and energy decision-making. All professors should keep in mind that the students over the course of the semester need to internalize how these principles and factors work together and are intertwined. Energy literacy occurs only when the student can apply a mental model of the various aspects of energy and when critical thinking based on the model becomes a part of the student's routine energy decision-making. The course is designed to help students develop and refine such mental models so that they can become energy literate students/citizens who objectively understand the implications of their daily decisions about energy and of decisions we make as a nation. Exposing students to contrasting points of view, followed by a class discussion on the reasons for the competing views, is also an important tool in helping the students form their own informed opinions.

During the 2013 spring semester at the University of Maryland (UMD), the Energy 101 team is testing the Model Curriculum by teaching a course based on it. The course applies a hybrid methodology utilizing Understanding by Design - UbD [Wiggins & McTighe, 2005]; Universal Design by Learning - UDL [Rose and Meyer, 2002]; and Evidenced Centered Design – ECD [Mislevy, 1999] that provides a focus on developing critical thinking skills. It also permits objective comparison of the content of the various versions of Energy 101 taught by different instructors and at different locations. The flagship course, the UMD I-series course was created by Dr. Idalis Villanueva and Dr. Leigh Abts of the University of Maryland as a new general elective, interdisciplinary undergraduate course BioE 289A entitled, "Designing a Sustainable World ", which Dr. Abts began teaching on January 25, 2013. Other courses based on the model curriculum are under development at Harford Community College outside of Baltimore and Cecil Community College in rural Maryland and may be offered as early as the end of this month.

Teaching materials, including syllabi, lesson plans and PowerPoint slides related to lectures are currently being developed for each course and could be posted on NTER for easy access and sharing (within the limits of copyright law and assuming Energy 101 professors are willing to share content they developed for their individual courses). With the open-source NTER tool, users also have access to advanced IT and graphics to create new materials that are relevant to their own needs and geographic region. A possible enhancement under consideration is to make existing NTER content that relates to a lesson easier to find by indexing it by Energy Literacy principle. Other team members are starting to create additional NTER modules that will be similarly indexed. Some will use an online version of the WaterShed House, University of Maryland's winning entry in the 2011 Solar Decathlon. The NTER Forum also can be used to post modules and other teaching materials, contribute ideas for modules and give feedback on posted materials.

About the Cover Image

The cover image is of the result of composite data acquired by NASA and NOAA satellites over nine days in April of 2012 and 13 days in October of 2012 and shows the continental United States at night and the light originating from city lights, gas flairs, auroras, and wildfires. **Credit:** NASA Earth Observatory/NOAA NGDC

COURSE OUTLINE

The Energy 101 course outline consists of five units; Introduction to Energy, Energy Basics, Energy Sources, Energy Technology and Practice, and Energy Policy and Decision Making. Each unit contains one or more of the seven Essential Energy Literacy Principles (1 through 7) and a number of their associated fundamental concepts (1.1, 1.2 and so on). The fundamental concepts in the energy literacy document were designed to be unpacked and used in a variety of combinations.

1. Introduction to Energy

Courses based on the curriculum generally should begin with an overview of the course goals and an introduction to the course syllabus including an articulation of the skills to be developed during the course. Exercises will introduce critical thinking and how it relates to the students' individual decisions, as well as how it is used in larger scale energy decisions, perhaps including those made by the university offering the course. To help set the course's tone as a practical rather than theoretical course, the first class can include an assignment that introduces the material to be covered and establishes a baseline of what the student knows. For example, students can be asked to develop a list of the most important ways they use energy and how energy affects their lives now and in the future, to refine the list after class discussion, and to consider as the course progresses whether they are using energy efficiently or inefficiently (or unnecessarily), the broader impact of their energy use, and if/how their use of energy has changed. Another activity could be to explore energy use on campus -- where and how energy is used, what entity or function uses the most -- and to identify the source(s) of that energy.

Energy will be described through a discussion of the limits of traditional definitions, thereby showing students that energy is a fundamental entity of the universe and defies definition. The formal laws governing energy will be introduced including natural limits on energy use and how energy moves through the Earth system. The difference between energy sources, fuels, and transport mechanisms will be introduced. Students will learn how pervasive energy is in all aspects of our lives. Through exercises, students will discover the energy fuel cycles, supply chains, and corresponding environmental and resource impacts. By the end of this section students will know that there are very real environmental limits to current levels of energy use worldwide both in terms of climate and water, but surging demand internationally as standards of living increase. Students will be introduced to the concept of inertia, to energy decision-making, and to the challenges and effects of changing direction in energy policy. Economic, political, environmental, inertial, and social influences on energy decision-making will also be introduced via generalization of individual cases. International aspects of energy policy including unequal use of energy, the aspirations of developing nations, and varying growth rates among and within countries may also be introduced. It is assumed that professors may also want to bring in outside experts to discuss topics relevant to students, such as careers in energy, industry trends, special skills training and policy issues.

Energy Literacy Principles Covered

1. **Energy is a physical quantity that follows precise natural laws**
2. **Physical processes on Earth are the result of energy flow through the Earth system.**
3. **Biological processes depend on energy flow through the Earth system.**

Associated Fundamental Concepts Covered

1.1 Energy is a quantity that is transferred from system to system. Energy is the ability of a system to do work. A system has done work if it has exerted a force on another system over some distance. When this happens, energy is transferred from one system to another. At least some of the energy is also transformed from one type into another during this process. One can keep track of how much energy transfers into or out of a system.

2.6 Greenhouse gases affect energy flow through the Earth system. Greenhouse gases in the atmosphere, such as carbon dioxide and water vapor, are transparent to much of the incoming sunlight but not to the infrared light from the warmed surface of Earth. These gases play a major role in determining average global surface temperatures. When Earth emits the same amount of energy as it absorbs, its average temperature remains stable.

3.6 Humans are part of Earth's ecosystems and influence energy flow through these systems. Humans are modifying the energy balance of Earth's ecosystems at an increasing rate. The changes happen, for example, as a result of changes in agricultural and food processing technology, consumer habits, and human population size.

2. Energy Basics

Students will learn the science basics related to energy in greater detail and compare the various energy forms and the extent to which they are unique, interchangeable, and transformable. They will learn about energy efficiency, embodied energy, and related concepts. Energy units of measurement and certain principles may be more easily conveyed and understood with 3D diagrams, infographics, animation, calculators and other visualization tools. This is what the NTER platform offers, and in this case an NTER module may provide a valuable complement to the course as a virtual lab or homework assignment. For example, a digital simulation of a "net-zero energy" house can demonstrate the transfer, resistance and storage of thermal energy, how individual elements of the house interact with each other and the local micro-climate, and how these separate components can be integrated and optimized to achieve a unified "whole-building system" that performs "better than the sum of its parts."

Energy Literacy Principles Covered

1. Energy is a physical quantity that follows precise natural laws

Associated Fundamental Concepts Covered

1.2 The energy of a system or object that results in its temperature is called thermal energy. When there is a net transfer of energy from one system to another, due to a difference in temperature, the energy transferred is called heat. Heat transfer happens in three ways: convection, conduction, and radiation. Like all energy transfer, heat transfer involves forces exerted over a distance at some level as systems interact.

1.3 Energy is neither created nor destroyed. The change in the total amount of energy in a system is always equal to the difference between the amount of energy transferred in and the amount transferred out. The total amount of energy in the universe is finite and constant.

1.4 Energy available to do useful work decreases as it is transferred from system to system. During all transfers of energy between two systems, some energy is lost to the surroundings. In a practical sense, this lost energy has been "used up," even though it is still around somewhere. A more efficient system will lose less energy, up to a theoretical limit.

1.5 Energy comes in different forms and can be divided into categories. Forms of energy include light energy, elastic energy, chemical energy, and more. There are two categories that all energy falls into: kinetic and potential. Kinetic describes types of energy associated with motion. Potential describes energy possessed by an object or system due to its position relative to another object or system and forces between the two. Some forms of energy are part kinetic and part potential energy.

1.6 Chemical and nuclear reactions involve transfer and transformation of energy. The energy associated with nuclear reactions is much larger than that associated with chemical reactions for a given amount of mass. Nuclear reactions take place at the centers of stars, in nuclear bombs, and in both fission- and fusion-based nuclear reactors. Chemical reactions are pervasive in living and non-living Earth systems.

1.7 Many different units are used to quantify energy. As with other physical quantities, many different units are associated with energy. For example, joules, calories, ergs, kilowatt-hours, and BTUs are all units of energy. Given a quantity of energy in one set of units, one can always convert it to another (e.g., 1 calorie = 4.186 joules).

1.8 Power is a measure of energy transfer rate. It is useful to talk about the rate at which energy is transferred from one system to another (energy per time). This rate is called power. One joule of energy transferred in one second is called a Watt (i.e., 1 joule/second = 1 Watt).

3. Energy Sources / Impact of Energy Production and Use

Here, students will learn how varied the possible energy sources are; their unique characteristics; which ones are suited for which uses; and about intermittency, energy storage, conversion and transmission losses, environmental and fuel life-cycle considerations including extraction and waste disposal, impacts of regulation, and other limits on use. It will objectively cover fossil, nuclear, geothermal, hydroelectric fuel cycle and renewable energy sources such as solar, wind and biomass. Students will explore the advantages, disadvantages, environmental impacts, and common misconceptions about various types of energy. This unit will teach renewable versus finite sources and how long various sources are estimated to be available at current levels of use. Impact of production and use of various types of energy on climate, water resources, air and water quality, wildlife habitats, and communities will also be considered. Modules can encourage innovative thinking about energy sources and energy conservation. Simple exercises that diagram the movement of matter through the atmosphere, lithosphere, and biosphere can allow students to see the conservation of mass principle as well as the impact of energy conservation in the real world.

Energy Literacy Principles Covered

2. Physical processes on Earth are the result of energy flow through the Earth system.

4. Various sources of energy can be used to power human activities, and often this energy must be transferred from source to destination.

6. The amount of energy used by human society depends on many factors.

7. The quality of life of individuals and societies is affected by energy choices.

Associated Fundamental Concepts Covered

2.2 Sunlight, gravitational potential, decay of radioactive isotopes, and rotation of the Earth are the major sources of energy driving physical processes on Earth. Sunlight is a source external to Earth, while radioactive isotopes and gravitational potential, with the exception of tidal energy, are internal. Radioactive isotopes and gravity work together to produce geothermal energy beneath Earth's surface. Earth's rotation influences global flow of air and water.

4.1 Humans transfer and transform energy from the environment into forms useful for human endeavors. The primary sources of energy in the environment include fuels like coal, oil, natural gas, uranium, and biomass. All primary source fuels except biomass are non-renewable. Primary sources also include renewable sources such as sunlight, wind, moving water, and geothermal energy.

4.3 Fossil and biofuels are organic matter that contains energy captured from sunlight. The energy in fossil fuels such as oil, natural gas, and coal comes from energy that producers such as plants, algae, and cyanobacteria captured from sunlight long ago. The energy in biofuels such as food, wood, and ethanol comes from energy that producers captured from sunlight very recently. Energy stored in these fuels is released during chemical reactions, such as combustion and respiration, which also release carbon dioxide into the atmosphere.

4.5 Humans generate electricity in multiple ways. When a magnet moves or magnetic field changes relative to a coil of wire, electrons are induced to flow in the wire. Most human generation of electricity happens in this way. Electrons can also be induced to flow through direct interaction with light particles; this is the basis upon which a solar cell operates. Other means of generating electricity include electrochemical, piezoelectric, and thermoelectric.

4.7 Different sources of energy and the different ways energy can be transformed, transported, and stored each have different benefits and drawbacks. A given energy system, from source to sink, will have an inherent level of energy efficiency, monetary cost, and environmental risk. Each system will also have national security, access, and equity implications.

6.1 Conservation of energy has two very different meanings. There is the physical law of conservation of energy. This law says that the total amount of energy in the universe is constant. Conserving energy is also commonly used to mean the decreased use of societal energy resources. When speaking of people conserving energy, this second meaning is always intended.

7.3 Environmental quality is impacted by energy choices. Energy choices made by humans have environmental consequences. The quality of life of humans and other organisms on Earth can be significantly affected by these consequences.

4. How Energy is used / Energy Technology and Practice

This unit will begin the application of what the students have learned. Content will vary depending on the focus of the course. For example, one school's Energy 101 course might include simple math and engineering problems that deal with heat pumps, air conditioning or the aging electric grid, while another might compare methods of oil and gas extraction, transportation systems, or the relationship between water and water quality and energy production and use. Concepts like resiliency, redundancy, useful life and quality of energy supply and delivery may be introduced. The purpose of the unit is to show an aspect of energy use that the students can relate to and the tradeoffs involved in production, energy use and conservation of other natural resources like water. Additional modules that apply principles and teach decision-making to address technological problems and issues will be used.

Energy Literacy Principles Covered

4. Various sources of energy can be used to power human activities, and often this energy must be transferred from source to destination.

Associated Fundamental Concepts Covered

4.2 Human use of energy is subject to limits and constraints. Industry, transportation, urban development, agriculture, and most other human activities are closely tied to the amount and kind of energy available. The availability of energy resources is constrained by the distribution of natural resources, availability of affordable technologies, socioeconomic policies, and socioeconomic status.

4.3 Fossil and biofuels are organic matter that contains energy captured from sunlight. The energy in fossil fuels such as oil, natural gas, and coal comes from energy that producers such as plants, algae, and cyanobacteria captured from sunlight long ago. The energy in biofuels such as food, wood, and ethanol comes from energy that producers captured from sunlight very recently. Energy stored in these fuels is released during chemical reactions, such as combustion and respiration, which also release carbon dioxide into the atmosphere.

4.4 Humans transport energy from place to place. Fuels are often not used at their source but are transported, sometimes over long distances. Fuels are transported primarily by pipelines, trucks, ships, and trains. Electrical energy can be generated from a variety of energy resources and can be transformed into almost any other form of energy. Electric circuits are used to distribute energy to distant locations. Electricity is not a primary source of energy, but an energy carrier.

4.5 Humans generate electricity in multiple ways. When a magnet moves or magnetic field changes relative to a coil of wire, electrons are induced to flow in the wire. Most human generation of electricity happens in this way. Electrons can also be induced to flow through direct interaction with light particles; this is the basis upon which a solar cell operates. Other means of generating electricity include electrochemical, piezoelectric, and thermoelectric.

4.6 Humans intentionally store energy for later use in a number of different ways. Examples include batteries, water reservoirs, compressed air, hydrogen, and thermal storage. Storage of energy involves many technological, environmental, and social challenges.

4.7 Different sources of energy and the different ways energy can be transformed, transported, and stored each have different benefits and drawbacks. A given energy system, from source to sink, will have an inherent level of energy efficiency, monetary cost, and environmental risk. Each system will also have national security, access, and equity implications.

5. Energy Policy and Decision-Making

This unit will cover the relationship between critical thinking about energy and the social sciences. Lessons on energy economics (internal costs and external costs such as health care and pollution remediation), psychology and human behavior, ethics, politics (including the effects of current law and subsidies), and sociology will encourage a deeper understanding of the energy implications of our daily decisions and of national policy decisions. Stories about how individual and group actions have made a difference can be included. During the final weeks of courses based on the Model Curriculum, NTER can be used to develop interdisciplinary group capstone projects (modules) where students from various backgrounds and interests bring their skills to the table, and group results are presented to the entire class as a symposium. Parts of this material will be embedded in the capstones and will be covered when the results of the capstones are presented to the class. Collectively, the presentations will simulate how energy decision-making occurs at the local, state, national, and/or international level and introduce the students to the complexities and limits of decision-making processes.

Energy Literacy Principles Covered

5. Energy decisions are influenced by economic, political, environmental, and social factors.

6. The amount of energy used by human society depends on many factors.

7. The quality of life of individuals and societies is affected by energy choices.

Associated Fundamental Concepts Covered

5.1 Decisions concerning the use of energy resources are made at many levels. Humans make individual, community, national and international energy decisions. Each of these levels of decision making has some common and some unique aspects. Decisions made beyond the individual level often involve a formally established process of decision-making.

5.2 Energy infrastructure has inertia. The decisions that governments, corporations, and individuals made in the past have created today's energy infrastructure. The large amount of money, time, and technology invested in these systems makes changing the infrastructure difficult, but not impossible. The decisions of one generation both provide and limit the range of possibilities open to the future generations.

5.3 Energy decisions can be made using a systems-based approach. As individuals and societies make energy decisions, they can consider the costs and benefits of each decision. Some costs and benefits are more obvious than others. Identifying all costs and benefits requires a careful and informed systems-based approach to decision making.

5.4 Energy decisions are influenced by economic factors. Monetary costs of energy affect energy decision making at all levels. Energy exhibits characteristics of both a commodity and a differentiable product. Energy costs are often subject to market fluctuations, and energy choices made by individuals and societies affect these fluctuations. Cost differences also arise as a result of differences between energy sources and as a result of tax-based incentives and rebates.

5.5 Energy decisions are influenced by political factors. Political factors play a role in energy decision making at all levels. These factors include, but are not limited to, governmental structure and power balances, actions taken by politicians, and partisan-based or self-serving actions taken by individuals and groups.

5.6 Energy decisions are influenced by environmental factors. Environmental costs of energy decisions affect energy decision making at all levels. All energy decisions have environmental consequences. These consequences can be positive or negative.

5.7 Energy decisions are influenced by social factors. Questions of ethics, morality, and social norms affect energy decision making at all levels. Social factors often involve economic, political, and environmental factors.

6.2 One way to manage energy resources is through conservation. Conservation includes reducing wasteful energy use, using energy for a given purpose more efficiently, making strategic choices as to sources of energy, and reducing energy use altogether.

6.3 Human demand for energy is increasing. Population growth, industrialization, and socioeconomic development result in increased demand for energy. Societies have choices with regard to how they respond to this increase. Each of these choices has consequences.

6.4 Earth has limited energy resources. Increasing human energy consumption places stress on the natural processes that renew some energy resources and it depletes those that cannot be renewed.

6.5 Social and technological innovation affects the amount of energy used by human society. The amount of energy society uses per capita or in total can be decreased. Decreases can happen as a result of technological or social innovation and change. Decreased use of energy does not necessarily equate to decreased quality of life. In many cases it will be associated with increased quality of life in the form of increased economic and national security, reduced environmental risks, and monetary savings.

6.6 Behavior and design affect the amount of energy used by human society. There are actions individuals and society can take to conserve energy. These actions might come in the form of changes in behavior or in changes to the design of technology and infrastructure. Some of these actions have more impact than others.

6.8 Amount of energy used can be calculated and monitored. An individual, organization, or government can monitor, measure, and control energy use in many ways. Understanding utility costs, knowing where consumer goods and food come from, and understanding energy efficiency as it relates to home, work, and transportation are essential to this process.

7.1 Economic security is impacted by energy choices. Individuals and society continually make energy choices that have economic consequences. These consequences come in the form of monetary cost in general and in the form of price fluctuation and instability specifically.

THE ENERGY 101 PROJECT TEAM

The 'Energy 101' project is primarily funded by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) and managed by the Association of Public and Land-grant Universities and the Oak Ridge Association of Universities. EESI and the University of Maryland are providing outreach, peer review, and content development.

The Association of Public and Land-grant Universities *(www.aplu.org) is the nation's oldest higher education association, serving 217 public research universities, land-grant institutions, state university systems, and education-related organizations. Member campuses enroll more than 3.6 million undergraduate and 1.1 million graduate students, employ more than 670,000 faculty and administrators, and conduct nearly two-thirds of all university-based research, totaling more than $34 billion annually.*

The University of Maryland *(www.umd.edu) is the state's flagship university and one of the nation's preeminent public research universities. Ranked No. 19 among public universities by U.S. News & World Report, it has 32 academic programs in the U.S News Top 10 and 73 in the Top 25. The Institute of Higher Education (Jiao Tong University, Shanghai), which ranks the world's top universities based on research, puts Maryland at No. 38 in the world and No. 13 among U.S. public universities. The university has produced six Nobel laureates, seven Pulitzer Prize winners, more than 40 members of the national academies and scores of Fulbright scholars. The university is recognized for its diversity, with underrepresented students comprising one-third of the student population.*

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