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Bioengineering a Sustainable World Unit Overview and Background

Humans have been extracting petroleum and using it to fuel a variety of processes for over 2,000 years. In 2017, the United States alone consumed a total of 7.26 billion barrels of petroleum products. As the human population continues to grow exponentially, we continue to burn fossil fuel, releasing millennials worth of sequestered carbon as carbon dioxide and are rapidly changing the atmosphere of our planet. To explore ways to make common practices more sustainable, researchers are using photosynthetic organisms to create products that are carbon neutral. One example of a sustainable product is biofuel that can be created using photosynthetic microbes like the green algae *Chlamydomonas reinhardtii*. When grown under the right conditions, these algae will store oil in their cells that can be extracted and used as biofuel.

To address the larger problem of increasing carbon emissions, we need a systems approach to identify a solution. A combination of scientific research and educational exploration is needed to better understand the problem of carbon emissions and work to find a variety of processes and products that are more sustainable. In this module, students learn about the multidisciplinary approach of bioengineering and how it can be applied to real-world scenarios. Students also learn about gene regulatory networks to understand the effects of environment on gene expression and how this could lead to the creation of sustainable products. Through exploring current biotechnologies and research, students participate in inquiry-based activities and labs that support student understanding of gene expression in changing environments.

Many broader topics need to be considered when exploring the goal of sustainable practices and products. These include economic feasibility, scaling, environmental sustainability, and practicality. Using green algae as a model organism to show how living organisms can be bioengineered to help reduce carbon emissions provides a platform for discussions regarding cross-curricular concepts. Students will be performing labs closely aligned with current research at the Institute for Systems Biology (ISB) through the work of Dr. Jacob J. Valenzuela. Students will be working directly with the same species of algae used at ISB to test how the algae can bioremediate wastewater, sequester carbon, and how the algae's phenotype changes with different environments.

Curriculum Summary

In this module, students will begin by learning about systems biology and by researching a current events article regarding bioengineering and sustainability. Next, students go through a case study introducing them directly to current research at ISB as well as gene regulatory networks. Students will perform at least one lab using green algae as a model organism to aid in their investigation of how to mitigate human carbon emissions. Available labs include analyzing the effect of a change in environment on gene expression, measuring carbon sequestration by algae, and measuring the ability algae to bioremediate wastewater. Finally, students will be able to construct a final project where they will pitch their own start-up biotech company with an idea of a product to help mitigate carbon emissions. Also included in the module are transcription and translation activities with a bioenergy theme and a more detailed study of gene regulatory networks.

Teacher Guides
Overview of the lessons available through this PowerPoint, summarizing the different concepts and activities of the module. Overall flowchart of the lessons and the sequence in which they should be presented can be found here.

Standards Addressed: The module has been aligned with NGSS standards as well as some literacy standards expressed. The overview of the standards addressed can be found on this document.

Lesson plans are available with more detailed explanations of how long certain activities and concepts should take to cover and complete.

Instructional videos are available to supplement your lessons: "*The Origin Story of Petroleum—where does our fuel come from?*" & "*Can We Bioengineer a More Sustainable World?*"

Lesson Outline

Lesson 1—Systems Biology & Climate Change. This lesson gives students an introduction to what systems biology is and how a multi-disciplinary approach is necessary to address problems as large and complex as climate change. Students will set up at least one lab and participate in activities related to carbon emissions mitigation.

Lesson 2—Bioengineering and Sustainability. This lesson provides students with an opportunity to perform a case study about biofuel research and gene regulatory networks as an introduction to bioengineering. The overall goal is to provide a general concept of regulation while also introducing the topic of biofuel as one example of a product that is sustainable. There are also Cornell notes available to encourage note-taking and concept checking with review questions. Students will either continue to take data for their lab or set up the lab now.

Laboratory Options—Between lessons 1 and 2 is a good time to set-up one of the labs. Available labs include a wastewater bioremediation lab, a carbon sequestration lab, and a lab exploring environmental effects on gene expression. Each lab uses green algae and relates back to bioengineering and sustainability concepts.

Lesson 3—Gene Regulatory Networks & The Effect of Environment. This lesson dives into the details of gene regulatory networks and uses examples of positive and negative control through proteins such as transcription factors that respond to environmental cues.

Lesson 4—Biotechnology and Solutions. This lesson goes into more details about the mechanisms of various regulatory networks and why they are important for expressing genes. The examples of the Lac and Trp operon are used. Students will be asked to read a scientific paper regarding gene regulatory networks to check their understanding and practice how to read a scholarly paper.

Cumulative Project. At the end of this module, students will work together in small groups to create a pitch for a new Biotech company that uses bioengineering to create an organism modified using CRISPR technology to help combat climate change (specifically, carbon emissions).

More Information

For more information regarding sustainable practices, including current research, check out this scientific journal, which is an open source journal that has a collection of studies related to biofuel. This graphic shows a summary of what algae are, why they are a good model organism, and what they can be used to create. It also might be helpful to use either this factsheet put together by the International Union for the Conservation of Nature, or this factsheet put together by the U.S. Department of the Interior regarding carbon sequestration as a method of mitigating climate change. Finally, this website offers links to other factsheets, brochures, studies, and curriculum all on the topic of biofuel and sustainable energy as well as this website from the U.S. Global Change Research Program that has resources and news updates.