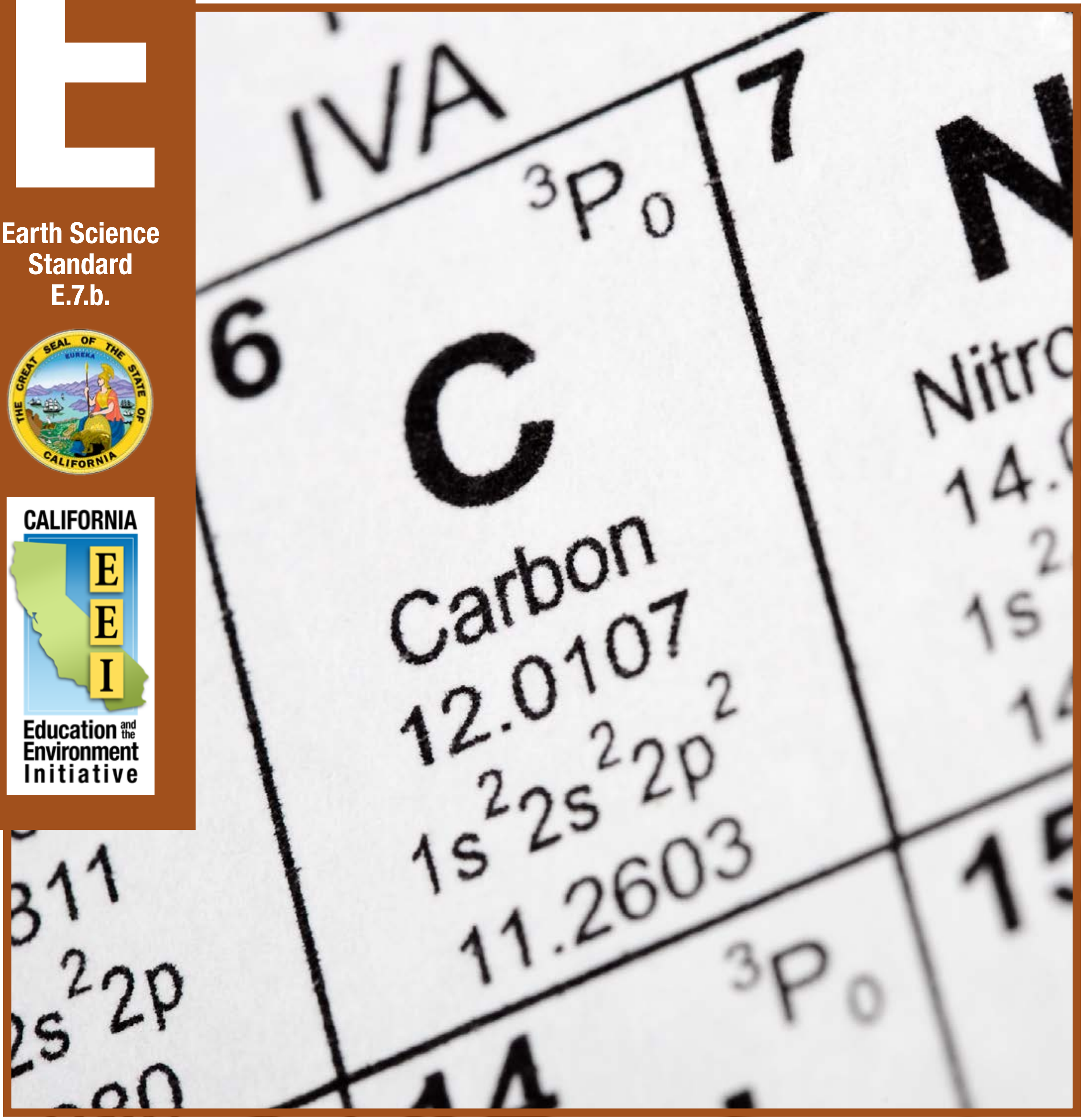
Student Edition

California Education and the Environment Initiative

E

Earth Science Standard E.7.b.



The Life and Times of Carbon

California Education and the Environment Initiative

Approved by the California State Board of Education, 2010

The Education and the Environment Initiative Curriculum is a cooperative endeavor of the following entities:

California Environmental Protection Agency

California Natural Resources Agency

California State Board of Education

California Department of Education

Department of Resources Recycling and Recovery (CalRecycle)

Key Partners:

Special thanks to **Heal the Bay,** sponsor of the EEI law, for their partnership and participation in reviewing portions of the EEI curriculum.

Valuable assistance with maps, photos, videos and design was provided by the **National Geographic Society** under a contract with the State of California.

Office of Education and the Environment

1001 I Street • Sacramento, California 95814 • (916) 341-6769

http://www.CaliforniaEEI.org

Contents

Lesson 1 Carbon: The Building Block of Life

Lesson 2 We Live in a Carbon-ated World

None required for this lesson.

Lesson 3 Carbon Cycling: Waste Not, Want Not

None required for this lesson.

Lesson 4 It Started with Fire

Lesson 5 Biofuels in the News

The following article originally appeared in the San Diego Union-Tribune on February 17, 2008. (It is reprinted here with author's permission.) Although the funding for biofuels research that the article attributes to President George W. Bush did not materialize, the federal government does provide numerous incentives and tax breaks to producers of biofuels and substantial funding for research. Fuel refiners are also required to blend biofuels into petroleum-based fuels, which provides additional government support for this industry.

The Promise of Biofuels: Hype or a Real Solution?

With gas prices approaching $4 a gallon and industries searching for new ways to reduce carbon dioxide emissions, biofuels—fuels, such as ethanol derived from corn and other plant sources rather than petroleum—are becoming an increasingly attractive option to help mitigate the impacts of climate change and reduce our oil imports.

The promise of powering our cars exclusively with green energy from plants prompted President Bush to ask Congress recently for $225 million for biofuels research—a 19 percent increase over this year's federal spending level. And it brought more than 300 scientists and business leaders from around the nation to a meeting here recently hosted by the University of California San Diego to discuss new ways of producing ethanol from plants and other promising avenues of biofuels research.

Cornfield

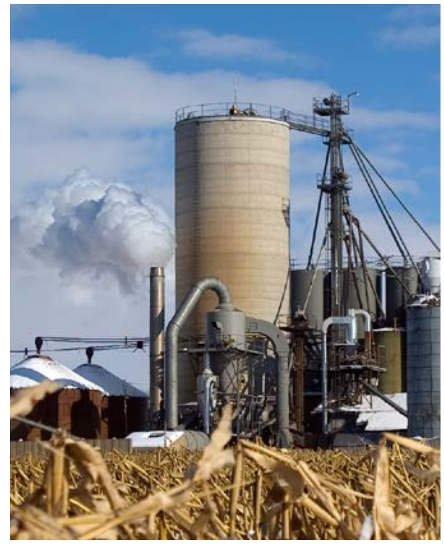
Everyone seems to be touting the benefits of biofuels these days: Midwestern farmers, environmentalists, state and federal legislators, Gov. Arnold Schwarzenegger, business leaders, venture capitalists and university scientists. But can corn-based ethanol—the primary focus of current biofuels efforts—deliver what we need to accomplish? And are the promises of biofuels more hype than real?

We now know that Earth's climate is changing, caused by the accelerating use of fossil fuels that started at the time of the Industrial Revolution. The dramatic changes in land use—the conversion of natural ecosystems to agricultural fields—that accompanied the growth of human population also contributed substantially by releasing carbon stored in the vegetation and in the soils. These activities caused an increase in atmospheric carbon dioxide that has not been seen in the past 400,000 years. This increase is responsible for the so-called greenhouse effect, the warming of the land and the oceans with resulting changes in wind, rain and storm patterns. The evidence supporting this interpretation is both overwhelming and unequivocal.

Biofuels can help mitigate this global climate change phenomenon because they are made from plants and algae that absorbed carbon dioxide in the process of photosynthesis. When we burn fossil fuels, we add carbon dioxide to the atmosphere, but burning biofuels releases carbon dioxide that was taken out of the atmosphere by plants or algae a few days, weeks or years earlier. So, we create a carbon cycle, helping to prevent further buildup of carbon dioxide in the atmosphere. The United States has a strong biofuels industry based largely on ethanol derived from corn grain and made possible by the high price of petroleum, generous farm subsidies and a stiff tariff on imports of sugar and ethanol.

Unfortunately, all biofuels are not created equal when we look at the extent to which they mitigate greenhouse gas buildup. The reason is that growing plants and converting plant material into biofuel also takes energy. And at the moment that energy comes mostly from electricity generated by fossil fuels. So much energy is required to produce the two main biofuels now being utilized in the United States—ethanol made from cornstarch and biodiesel made from canola and soybeans—that the net effect of their use on greenhouse gases is negative rather than positive.

The reasons are complex: corn and canola require a lot of nitrogen fertilizer to grow, and making nitrogen fertilizers is very energy intensive. Furthermore, whenever nitrogen fertilizer is used soil bacteria cause nitrous oxide to be released into the atmosphere. In the case of corn ethanol, distilling the ethanol requires energy. We can't make ethanol pipelines because ethanol is corrosive, so ethanol has to be transported in trains and trucks. For these and other reasons, the greenhouse gas balance—greenhouse gases removed from the atmosphere minus greenhouse gases released—is unfavorable for corn ethanol. In Europe, opposition to biofuels derived from food crops is already developing because they contributed to the recent rise in food prices. When fuel is derived from crops, food prices rise. Also, when croplands are converted for growing biofuel crops, a rise in food prices is unavoidable.



Ethanol factory

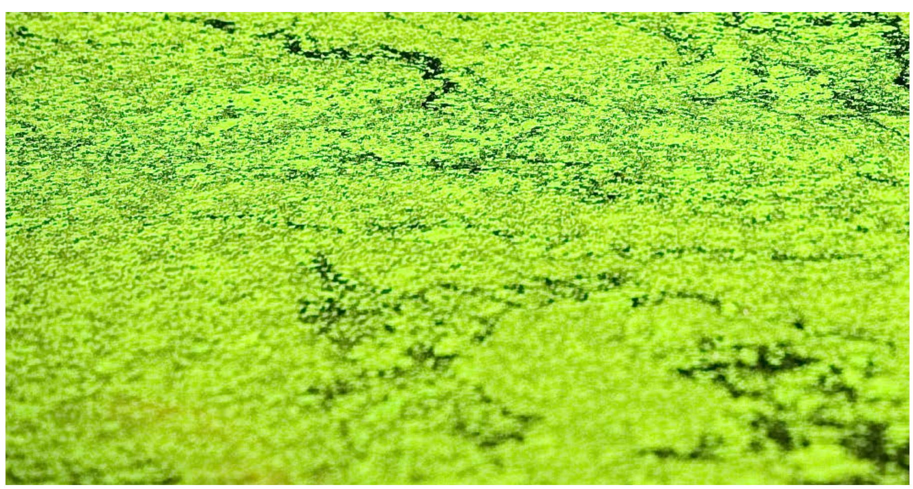
Fortunately, new technological developments are on the horizon. Ethanol can also be made from cellulose, the large linear molecule of plants consisting entirely of glucose that is the most abundant natural material in the world. Cellulose is the main ingredient in wood and in the new so-called biomass crops, such as *Miscanthus* (a large perennial grass) that do not require much nitrogen fertilizer and can have yields of 15 tons of biomass per acre when grown on good soils. The University of California at Berkeley has major research projects funded by the State of California and British Petroleum to develop the processes that convert cellulosic biomass into biofuels.

Scientists reported at our biofuels conference that sugar can also be fermented directly into gasoline-like molecules, such as alkanes, that do not need to be distilled. This would require us to create new superbugs. Remember the superbugs that ate oil spills? Our new superbugs would produce oil-like molecules for transportation.

Also, oil can be produced by microalgae living in shallow ponds using the nutrients in municipal wastewater. With such plant and algal sources and with new industrial processes and fermentations, we could have a true greenhouse gas neutral transportation system that prevents further buildup of carbon dioxide and the two other greenhouse gases released as a result of agricultural practices—methane and nitrous oxide—into the atmosphere. Indeed, the other greenhouse gases have to be counted as well. Jeff Severinghaus, of UCSD's Scripps Institution of Oceanography, reported at the meeting that for those crops that require nitrogen fertilizers, such as corn, canola and switchgrass, the release of nitrous oxide by soil bacteria may negate the positive effect of carbon dioxide absorption by photosynthesis.

So, when can we implement those solutions that promise to reduce greenhouse gases? Major technological breakthroughs are still needed to make these biofuels a reality. For one, the new crops need to be bred and selected—domesticated—for high biomass production. We still need to find the best genes and create the most efficient bacteria that would carry out these novel fermentations to produce alkanes rather than ethanol. We also need to develop more economical methods for the large-scale cultivation of algae and ways of extracting the new fuel molecules. Unfortunately, research on plants, algae and microbes has been woefully underfunded for decades as the nation focused its research dollars on human health and diseases.

By the end of the conference many in the audience realized that stark choices are being forced upon us. Fuel or tortillas, beef or biodiesel, which shall it be? When our lawmakers and the public at large understand that such choices are on our doorstep, then this funding trend could be reversed. Hopeful signs are the president's proposed budget already mentioned and a recent report by the National Research Council urging much greater funding for plant genetics, the basis of all crop improvement for food, fuel or fiber.



Algal bloom in pond

What should our focus be here in Southern California where transportation accounts for 40 percent of carbon dioxide release? Two research and development goals are clearly within the grasp of the University of California, San Diego and other San Diego-area scientists: oil produced by microalgae and novel fermentations that convert cellulose-derived sugars into oil-like molecules. Our intellectual resources include world-renowned microbiologists, geneticists, engineers and experts on algae. San Diego biotechnology companies, such as Synthetic Genomics, Verenium and Sapphire Energy have already acquired impressive expertise. We also have some unusual, but ideal, physical resources—degraded land around the Salton Sea that has become unsuitable for agriculture, but suitable for algae ponds—and abundant sunshine. The R&D (research and development) done right here in San Diego can help our local energy company, Sempra Energy Utilities, meet California's mandated climate change guidelines for renewable energy.

Sugar cane

So, are biofuels hype or can they be a real solution to climate change and carbon dioxide abatement? They will certainly play an important role, but let's not ignore the fact that society needs to simultaneously undertake many other initiatives to reduce carbon dioxide emissions and stabilize the climate. We will need to retrofit and redesign our buildings, emphasize mass transit, capture the carbon dioxide that is now emitted from our power plants and greatly increase the energy efficiency of all industrial processes. Although some biofuel crops can be grown on marginal soils not now used for agriculture, when such lands are put to the plow substantial amounts of carbon dioxide are released by the decomposition of the vegetation and the soil organic matter.

The scientists and business leaders attending our conference came to the realization that these are challenging times. And those of us at UCSD and other research institutions on the Torrey Pines mesa who can contribute to the long-term development of new biofuels are now eager to get to work and meet that challenge. This is one case where biologists really can make a difference by working with chemical engineers and ecologists to solve a major societal problem.

Article by Dr. Maarten Chrispeels and Dr. Steve Kay. Dr. Chrispeels is a professor in UCSD's Division of Biological Sciences. Dr. Kay is dean of UCSD's Division of Biological Sciences.

Pasture Patties, Meadow Muffins, Cow Pies, and Buffalo Chips

The Great Plains were once home to tens of millions of American bison, more commonly called "buffalo."

These animals traveled in great herds constantly in search of fresh grass. It was not hard to track a buffalo herd: they left behind a mile-wide trail of chomped grass and "buffalo chips"—the inevitable pie-sized droppings that come after an herbivore (plant eater) eats a good meal.

Early settlers had many names for these large droppings: "pasture patties," "meadow muffins," "cow pies" and "buffalo chips" are just a few. Across the treeless Great Plains, these dried droppings were gathered like firewood and used as fuel to warm a weary traveler or to cook the evening meal. Animal chips burn surprisingly well—especially those from grass-eating herbivores, such as buffalo, cattle, wildebeest, elephants, and others. Like corn ethanol or firewood, animal dung is a form of carbon-based biofuel.

Women in northern France in the 1900s gather and dry dung

Most people in the United States are able to heat their homes by turning up the thermostat that tells the furnace or boiler to kick up the heat. We flip the light switch in our kitchen, pop yesterday's leftovers into the microwave, and "zap," we have a hot meal. "Cooking out" often means lighting a gas or charcoal grill, or maybe roasting marshmallows or hot dogs over a wood fire during a campout. But today, in the United States, "go gather some kindling" never means filling a basket full of dried cow manure.

It is hard for us to imagine cooking food and boiling water over animal dung, but 2.4 billion people still do this today. Most people who rely on dung as fuel live in rural areas of developing countries where electricity is not available, is too expensive, or is unreliable. In regions with trees, firewood is preferred—for obvious reasons. In many regions, there are not enough fallen limbs or driftwood to go around, so people cut scarce trees for firewood. This has led to deforestation in many regions, such as Pakistan (a dry and mountainous region), Malaysia (tropical islands), and Madagascar (an island off the coast of eastern Africa). In Madagascar, only 10% of the forests remain. The loss of even a few trees in dry regions makes dry conditions worse: without vegetation and tree roots to hold soils together, once-fertile land becomes sandy and can lead to desertification—changing arable (farmable) land to desert.

American Bison or "Buffalo"

It all started with fire: ancestors to *Homo sapiens* burned wood nearly 2 million years ago. When wood or other organic matter is heated in the absence of air, charcoal is created. This black residue was first used about 8,000 years ago. Because this concentrated carbon fuel was able to burn very hot, blacksmiths used charcoal to heat metal to get it hot enough for shaping. The discovery of uses for coal came about roughly 3,000 years ago. The development of the steam engine in the mid 1700s made coal the most common energy source. Today, coal is used to produce 40% of the world's electricity, and petroleum gasoline or diesel is used in most of our automobiles and trucks.

However, all carbon energy sources are not equal: some sources contain more carbon than others. Compared to wood, dung is a loosely packed, less dense material. The small amount of carbon in dung burns faster than the more densely packed carbon in wood. Charcoal contains more carbon than wood, and fossil fuels are the result of extremely compacted plant material. This means that, pound for pound, fossil fuels are a more efficient source of energy than dung or wood. (Energy efficiency refers to the amount of energy produced during burning.) Burning dung and wood also releases soot and pollutants that are dangerous to inhale. In countries where people depend on firewood and charcoal for heating and cooking, the second leading cause of death (after diseases carried by polluted water) is respiratory diseases related to exposure to the harmful pollutants from burning these smoky, inefficient fuel sources.

In addition to carbon-based energy sources being unequal to each other with regard to energy efficiency, there is another key difference between them: their age and how long they have been or will be a part of one reservoir. What does this mean? Turn to a partner and discuss how carbon can be "young," "old," or even "ancient." Consider this: your metabolism burns carbohydrates with the same release of energy (and carbon dioxide) as if you had lit the food with a match. In fact, the calorie content of foods is determined by drying and burning the foods in a controlled space to reveal how much heat is generated. Decomposition of biomass is also a slow burning process. While the temperature of the burn does not produce flames, decomposition releases the same heat and carbon dioxide (and methane and other carbon gases) as burning. This is why some people say burning biomass does not add carbon dioxide to the atmosphere—because it would eventually get there through decomposition.

You might want to start your discussion by comparing a cow pie to a lump of coal. Where did the energy originate from? Where did it go? How long was it there before people burned it? Where does the carbon go after it has been burned? What would happen to the carbon source if it was not intentionally burned by humans? How does burning fossil fuels versus biomass affect the reservoirs in the carbon cycle differently?

Villagers collect firewood for fuel

Redesigning Life to Make Ethanol

MIT's *Technology Review*, Saturday, July 1, 2006

Producing ethanol fuel from biomass is attractive for a number of reasons. At a time of soaring gas prices and worries over the long-term availability of foreign oil, the domestic supply of raw materials for making biofuels appears nearly unlimited. Meanwhile, the amount of carbon dioxide dumped into the atmosphere annually by burning fossil fuels is projected to rise worldwide from about 24 billion metric tons in 2002 to 33 billion metric tons in 2015. Burning a gallon of ethanol, on the other hand, adds little to the total carbon in the atmosphere, since the carbon dioxide given off in the process is roughly equal to the amount absorbed by the plants used to produce the next gallon.

It's Corn vs. Soybeans in a Biofuels Debate

Adapted from *New York Times*, July 12, 2006

The study published by the National Academy of Sciences found that neither ethanol nor biodiesel can replace much petroleum without having an effect on food supply. If all American corn and soybean production were used to make biofuels, that fuel would replace only 12% of our gasoline needs and 6% of diesel needs, the study notes. Researchers in Minnesota write that with the expected doubling of worldwide need for food within the next 50 years and an even greater expected need for transportation fuels, "there is a great need for renewable energy supplies that do not cause a lot of harm and do not compete with worldwide food supplies."

Food Versus Fuel

Washington Post, December 12, 2007

During the past year, prices of basic grains, such as wheat and corn have soared… It is the extra demand for grains to make biofuels, driven heavily in the United States by government tax subsidies and fuel mandates, that has pushed prices dramatically higher. Since 2000, the share of the U.S. corn crop devoted to ethanol production has increased from about 6% to about 25%—and is still headed up.

Farmers benefit from higher prices. Up to a point, investors in ethanol refineries also gain from the mandated use of corn ethanol (though high corn prices have eroded or eliminated their profits). But who else wins is unclear. Although global biofuel production has tripled since 2000, it still accounts for less than 3% of worldwide transportation fuel, reports the U.S. Agriculture Department. Even if all U.S. corn were diverted into ethanol, it would replace only about 12% of U.S. transportation fuel, according to one study.

Biofuels became politically fashionable because they combined benefits for farmers with popular causes: increasing energy "security" and curbing global warming. But substituting corn-based ethanol for gasoline results in little reduction in carbon dioxide emissions. Indeed, the demand for biofuels encourages deforestation in developing countries; the *New York Times* recently reported the clearing of Indonesian forests to increase palm oil production for biofuel.

The Promise of Biofuels—Hype or a Real Solution?

Adapted from an article by Maarten Chrispeels and Steve Kay,
San Diego Union-Tribune, Feb. 17, 2008

But, all biofuels are not created equal. If we look at the amount of energy needed to produce different types of ethanol, some are better than others. The reason is that growing plants and converting plant material into biofuel also takes energy. And at the moment that energy comes mostly from electricity generated by fossil fuels. So much energy is needed to grow and produce corn ethanol, that this biofuel option does not reduce carbon dioxide emissions when compared to fossil fuels. The reasons are complex: corn needs a lot of nitrogen fertilizer to grow, and making nitrogen fertilizers is very energy intensive. In the case of corn ethanol, distilling the ethanol requires energy. We do not have ethanol pipelines, so ethanol has to be transported in trains and trucks. For these and other reasons, the greenhouse gas balance—greenhouse gases removed from the atmosphere minus greenhouse gases released—is unfavorable for corn ethanol. In Europe and in other countries, many people and governments are against making biofuels from food crops, such as corn, because they can cause food prices to go up. The good news is that new technology for making biofuels is being studied around the world. One feedstock that looks promising is ethanol made from cellulose. Cellulose is the main ingredient in wood and in the new so-called biomass crops, such as switchgrass, that do not need fertilizer.

So, when can we start using some of these options that promise to reduce carbon dioxide emissions? First, we will need to improve our technology so that the energy to produce better biofuels is not wasted. We need to continue to develop corn and other crops that produce high yields because with an ever growing population, we need these crops for food, as well as fuel. We also need to finish the work started on developing ethanol from switchgrass and other cellulose.

The reality of some of these biofuel options is that in the past, this type of research has not been well funded. It is clear that hard choices are going to be made: fuel or tortillas, beef or biodiesel, foreign oil or home-grown biofuel, which shall it be? When our lawmakers and the public at large understand that such choices are on our doorstep, then the problem with a lack of funds for biofuel research could be turned around.

California Education and the Environment Initiative

Printed on post-consumer recycled paper