

Starch Yer Engines

KERNEL POWER: Ethanol Fuel from Corn

Summary:

In the previous lesson, students learned how corn is industrially refined and separated into its specific components, one of the most useful being starch. They had the opportunity to detect the high quantity of starch that is present by manipulating corn in a simplified version of the wet-milling process. Students understand the structure of starch granules, and are now ready to apply this knowledge to a practical scenario with a real and meaningful context. This lesson involves students learning about a hot topic in the agricultural, industrial, environmental, and political arena: renewable energy from organic materials. Students will experiment with fermentation and distillation to see how corn can be used efficiently and cleanly as a fuel.

Changing the sugars and starches in corn kernels to ethanol is a complex process and has become well established as a mix of technologies which includes microbiology, chemistry, and engineering. It is an appropriate topic for issues-clarification and problem solving activities which involves students in considering the connection between agriculture and consumers.

Background Information:

In the wet mill process, instead of initially grinding the corn, it is soaked or "steeped" to separate the grain into its many parts. The starch is fermented into ethanol, similar to the dry mill process or processed into corn starch or corn syrup. The germ is processed for corn oil. The fiber and concentrated steeping liquid are co-dried and sold as corn gluten feed to the livestock industry. The gluten (protein) is dried to produce gluten meal, a highly sought after feed ingredient for poultry.

Ethanol or ethyl alcohol ($\text{CH}_3\text{CH}_2\text{OH}$) in its pure or neat form is a colorless, water-like liquid with a mild odor which boils at 78°C . Because of the way the hydroxide (OH) is bonded to the

Grade Level: Middle School

Goal: Ethanol produced from Wisconsin corn illustrates that science and technology can provide us with new products and new uses for products. After sorting out the facts and procedures of corn starch fermentation, students can reach their own conclusions about using ethanol as a renewable fuel.

Key Concepts: energy sources, fermentation, enzymes, chemical change, molecules, compounds, conservation of mass principle, fuel, biomass, higher-value products, alcohol.

Objectives: Upon completion of this lesson, students will:

1. *explain* why corn is considered a biodegradable, renewable resource.
2. *build models* of sugar, carbon dioxide, and alcohol molecules.
3. *learn* that complex sugar molecules must be broken down with enzymes before fermentation can occur.
4. observe a chemical reaction from yeast, corn syrup, and water and predict future behavior.
5. *create* real, working ethanol fuel in a laboratory setting.
6. *brainstorm* ways to address real-life concerns in the ethanol industry, such as what to do with the byproducts of the fermentation process.

Teaching Location: Classroom with lab equipment and small groups arrangement. If available, field trip to an ethanol distillery would be appropriate.

Lesson Time: up to four sessions of 85 minutes each. Discussion topics or writing activities not completed in class may be homework.

Subject Areas for Infusion: Science, Social Studies, Consumer Economics, English

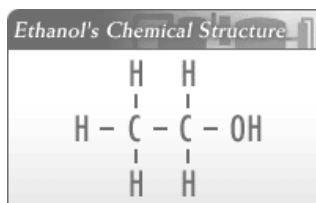
Standards: *Environmental Ed:* A.8.1-A.8.6, B.8.10, B.8.14, B.8.16, D.8.2

Science: A.8.1, A.8.6, B.8.6, C.8.1, C.8.5-C.8.9, D.8.1-D.8.4, G.8.3, H.8.3

carbon, ethanol has no basic or acidic properties. When dissolved in water it is neutral and has a pH of 7. It is a renewable alcohol fuel made from abundant agricultural resources, primarily corn.

Through a fermentation and distillation process, the starch is converted to sugar and then to alcohol. The process of fermentation is comparable to the respiration of food nutrients in many animals and plants. In fermentation, the yeast releases ethanol and carbon dioxide. In respiration, continuation of the breakdown yields carbon dioxide, water, and energy. In fermentation, the ethanol retains much of the energy that was originally present in the sugar and, while inefficient for the yeast, explains why ethanol is an excellent fuel.

Ethanol has many advantages over gasoline including producing fewer air toxins and ozone-forming emissions than gasoline, as well as reducing our dependence on imported oil. The use of ethanol blends reduces carbon monoxide levels by 30 percent.



In addition to ethanol, fermenting the corn's sugars with yeast creates carbon dioxide as a by-product (which is captured and sold for use in carbonated beverages and in the manufacture of dry ice).

Materials: toothpicks, gumdrops (black, white, red), yeast, water, corn syrup, clean 2-liter bottle, funnel, metric beaker, gloves, several balloons per group, lab notebooks, appropriate overhead photographs or notes, all materials for Activity 3 (opt.)

Set-Up: As preparation for the initial observation activity, the teacher should gather the following materials for each bottle experiment: one package of yeast, water, corn syrup, clean 2-liter bottle with label removed, balloon (that has already been stretched a bit), funnel, metric beaker, rubber gloves, sink or bucket. Note: this initial activity requires making observations throughout a 24-hour period. The fermentation process takes time! Since there is not enough time in the school day to devote to this kind of meticulous examination, the teacher might choose to have at hand several already-prepared yeast/corn syrup/water mixtures in bottles (w/ balloons over them) as they appear at various time intervals, such as 1 hour, 2 hours, 12 hours, and 24 hours.

For each group's experiment, the teacher has placed the package of yeast, water, and corn syrup in anonymous containers marked A, B, and C respectively.

Procedure:

Introduction: Discuss what was learned in the previous lesson regarding starch. Remind students that starch is a complex sugar and is used as energy for the plant. Plants store sunlight in the form of chemical energy. Through photosynthesis, plants convert radiant energy from the sun into chemical energy in the form of glucose (which is a kind of sugar). It might be appropriate to draw a diagram of photosynthesis as a reminder.

Show pictures on an overhead that represent non-renewable and renewable energy sources. The students should review those terms and offer additional examples.

Vocabulary:

Coal, oil, and natural gas are *non-renewable energy* sources. Some *renewable* sources of energy include solar, wind, biomass, hydroelectric, geothermal, and tidal energy.

Biomass refers to organic plants or animal matter.

Fermentation is a process by which many organisms derive energy from sugar. Sugar is changed to ethanol and carbon dioxide.

Monosaccharides are simple sugars.

The *starch* of the corn contains carbon, hydrogen, and oxygen.

Anaerobic conditions means no oxygen is involved.

Enzymes are naturally occurring chemicals that help to promote biochemical reactions. They serve as *catalysts* to break the starch down into simpler sugars.

Mention the Conservation of Mass principle, which will be explored in today's lab: "Matter cannot be created or destroyed in a reaction." Tell students to keep these in mind as they learn more about the fabulous power of Wisconsin corn.

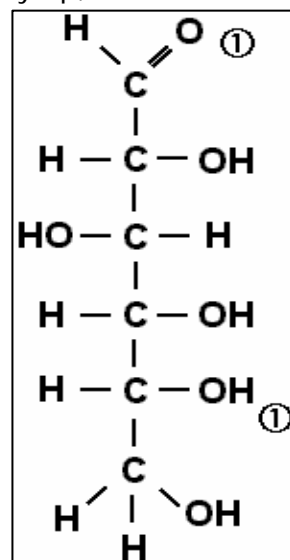
Activity 1:

- 1) Students enter the classroom and sit in small groups with their science journal and pencils. One student from each group gathers the carefully organized and laid-out materials from the teacher (see *Set-Up*). The teacher instructs each group to pour 2 cups (500 mL) of B into the 2-liter bottle. They are to add to it the contents of container A and swish the bottle to mix the ingredients. Then one group member places a stretched, deflated balloon over the mouth of the bottle.
- 2) At this point the students stop to examine the "reaction" closely. They are to discuss observations with their group members and record observations in their journals mostly about what they see, but if applicable, also what they smell and perhaps hear. Descriptions should include answers to questions such as: *what color is the mixture? Is the mixture transparent, translucent, or opaque? Is there any movement in the water? Describe it.*
- 3) Students then remove the balloon and place the funnel in the mouth of the bottle. They add $\frac{1}{4}$ cup (50 mL) of liquid C and mix the contents once again. As before, the balloon goes over the mouth of the bottle. The same questions as before should be addressed within the group and articulated in their journals. What has changed? With the large group, each group shares these initial observations. The teacher also poses these questions: what happens to the balloon and the mixture? Are these gas bubbles evident in the mixture? In what way is the balloon starting to change? What might this indicate?
- 4) For the next five to ten minutes, the group makes more detailed observations. They should notice that foam and gas bubbles are rising to the surface of the mixture, and the balloon is expanding and inflating because it is trapping the gas that's being produced. During this time as well, the students should begin to make predictions about how this experiment would continue if observations were made throughout 24 hours. What, if anything, would cause the reaction to stop? To get at the heart of making such predictions, the students need to start making hypotheses about what is going on in the bottles. At this point, students may use their background knowledge to discern what the "mystery" materials were that were used in this experiment. The teacher will circulate to gauge students' understanding and reasoning.
- 5) Discuss predictions in a large group. Responses might include ideas such as "the particles of the substances are speeding up and bouncing off of each other, so they'll stop when they get tired—in a half hour or so" or "the powdery stuff is getting broken down into tiny bits by the thick liquid, so it'll stop when it's broken down as tiny as can get—probably a few days."
- 6) The teacher will then actually show to the students her various sample bottles (or photos) that had been prepared beforehand. As a class, students will make objective observations about the bottles' contents and the balloons at the 1 hour, 2 hours, 12 hours, and 24 hours stages. Perhaps the students could make a graph that quantitatively describes one or two aspects of this bio-chemical reaction (such as balloon size could be created by the class).

- 7) The students will now have a chance to change their hypothesis, given the new, additional information. Within their groups, the students will have to synthesize their thoughts into a visual diagram to show and explain to their peers. Each group comes to the board to present their initial “theory” to the class.
- 8) The teacher then sheds light on this lesson by reminding the students of the previous days’s exploration of W1 corn. As review, the class discusses the process of separating the starch from the corn for the purpose of creating higher value products. Together they remember how starch molecules are in fact polymers, meaning in this case that they are repeating chains of sugar molecules that can be broken down through chemical processes. The purpose of the explorations of today’s lesson are to see what kind of products can actually be made from this sugary/starchy substance. As they know, starch particles react in very interesting ways under different conditions and when various substances enter the equation. As they will see, corn’s usefulness in our society extends well beyond the cob!

Activity 2 (a continuation):

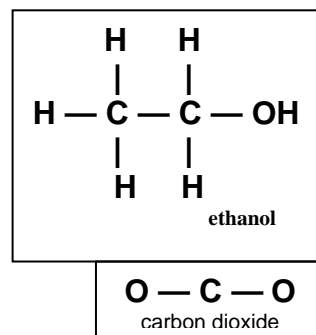
- 1) Inform the students that the materials used in the previous experiment were actually corn syrup, yeast, and water. The corn syrup is a product of the starchy part of the kernel, which has been chemically processed to exist as a complex sugar. The yeast was regular baking yeast used often in creating bread. Students might already know that yeast is a leavening agent that helps the dough to rise by filling in the gaps with air.
- 2) Ask students to recall what happened when the yeast was added to the water. (No reaction took place—it mixed around and some settled at the bottom. The balloon didn’t change.) The students then respond with their observations about what took place when the corn syrup was added to this mixture. (Gas bubbles form and balloon started to puff up somewhat.) Tell the students that the yeast uses the sugar as food. It’s like fuel for the yeast-- similar to the way that our bodies use sugar (and similarly, starch) to give us energy. The term used to describe the yeast breaking down the corn syrup is *fermentation*.
- 3) The students are going to form a model of the molecules that are in the corn syrup. This model is of glucose (the primary kind of sugar naturally found in corn). The starch in the corn, and consequently the sugar that’s produced, in this case as corn syrup, is made entirely of carbon, hydrogen, and oxygen. The way they are arranged and connected together is a naturally occurring pattern—this is what essentially distinguishes it as a sugar molecule (or “corn starch particle” here). The teacher passes to each student 6 red gumdrops, 12 black gumdrops, 6 white gumdrops, and handful of toothpicks. (Note: the students may catch the irony that the model itself is being constructed out of corn starch and corn syrup product.)
- 4) Instruct students to build their models by simultaneously drawing the model at right on the board. Tell them to attach the 6 red gumdrops all in line in a row. They are the carbon. Then, on the four middle carbons, attach a toothpick to both sides. On the top (or left) carbon, attach two toothpicks diagonally sticking out. On the bottom (or right) carbon, attach 3 toothpicks diagonally. Where there are OH molecules together, the candies can be placed next to



each other on the toothpick to simplify the model.

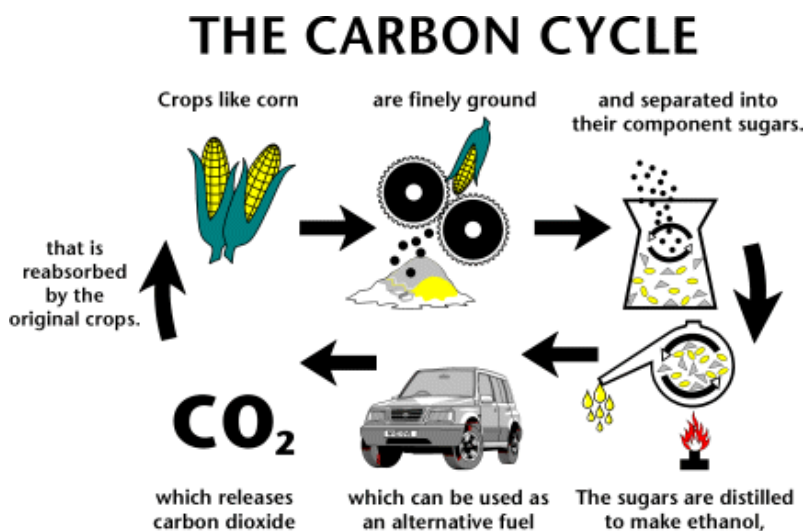
- 5) Explain: When the yeast comes along, the fermentation process begins and the corn syrup breaks down into two substances. Ask students to brainstorm what these substances might be based on the experiment. They should recall that one byproduct is a gas, and the other is a liquid (which doesn't look all that changed). The teacher reminds the students that in chemical reactions, matter can't be created or destroyed (this is a principle they have learned about, in general, in previous science explorations). Therefore, we have to use all of these same elements, and the exact number of them, in the "after" stage of the model (after the syrup was broken down).

- 6) Tell the students to carefully remove the gumdrops from their current arrangement within the corn syrup model. This takes up energy to do— it's a tricky and sticky process! In the same way, the *yeast* requires energy (from the sugar) to do this as well. Using the same gumdrops (with maybe a few more toothpicks (chemical bonds)), the students will create two carbon dioxide molecule models and two ethyl alcohol (ethanol) molecule models. These are the products of fermenting sugars. The gumdrop models should each look as such:



- 7) Explain: In the reaction, energy is released from these organic molecules in the absence of oxygen. The carbon dioxide escapes as a gas. What remains then is an alcohol, called ethyl alcohol or "ethanol" for short, which actually still *retains*

much of the energy that was originally present in the sugar. That is why alcohols are still very good fuels after the fermentation process. In addition, this is why ethanol is a valuable alternative fuel for our society (to power cars and other machinery). Corn, as an organic material, is biomass, which means that it has stored solar energy in the



form of chemical energy. This cycle can be summarized with the diagram above. source: www.eia.doe.gov/kids/renewable/biomass.html

Activity 3 (optional): Note: Actually changing corn to pure and useable ethanol requires many steps. The next activity requires students to participate in creating a classroom version of real ethanol fuel. Since this is a time consuming and rather hazardous experiment, it is preferable that the teacher this activity rather than the small groups making their own batches. Because this procedure requires waiting for several days, as before, the teacher will have an already-prepared batch of the materials to substitute to fill in the time gaps. This part requires quite a significant portion of time because this elaborate process should include discussion, clarification, and occasions to make specific connections to the opening activity.

The following experiment is adapted partially from the Illinois Corn organization's website (www.ilcorn.org/education) and partially from the Clean Fuels Coalition/Nebraska Ethanol Board's ethanol curriculum website (www.ne-ethanol.org/ethanolcurriculum.pdf).

Ethanol Production All-class Lab

Do not attempt it without the proper laboratory equipment, and everyone should follow appropriate lab safety procedures.

Preparing the malt:

First, the starch in corn must be broken down into simple sugars (like the glucose model previously diagrammed) before fermentation can occur. In earlier times this was done by chewing the corn. This allowed the salivary enzymes to naturally break down the starch. The teacher should pass out some raw corn kernels in paper cups for the students to munch on and salivate over. Fool the kids into thinking they're all going to spit their corn juices into the giant beaker! The teacher *should* then mention (unless she opts for the spitting version) that this step is achieved nowadays by cooking the corn and adding enzymes (specifically alpha-amylase and gluco-amylase) to break it down. They function as *catalysts* and help speed up the chemical changes. In this part of the experiment, the class will prepare and use the enzymes from the new sprouts of corn kernels.

The sprouting process in a seed produces enzymes that will convert starch to sugar. (This eliminates having to add enzymes to the mash. It's a more natural process.) About two weeks prior to the lab make a malt in which corn is sprouted to a length of about one inch. Soak corn seeds in a pail of warm water for 24 hours. Drain, add more warm water, and drain again after 15 minutes. Spread the soaked seeds on a wet towel, cover with another wet towel and a plastic sheet (keeps towels moist). When sprouts reach a length of one inch, remove sprout and kernel from towels and let dry. When malt is thoroughly dry, it can be ground for use in the mash.

Preparing the mash:

Materials: thermometer, stirring rod, distilled water (preheated and room temperature), balance, beakers (or kitchen pans), Erlenmeyer flasks, lab toweling, pH paper, sulfuric acid, burner apparatus (or hot plate), safety glasses, corn (shelled, meal, grits, or flour), grinding apparatus (rocks, boards, manual grinder).

Procedure:

- 1) In a beaker mix 50g of corn with 300 ml of preheated distilled water. Corn mash can be obtained at local feed mills and stores; it's about the consistency of coarse sand.
- 2) Add 1 or 2 drops of sulfuric acid to adjust pH to 5. (This step should be done by the teacher for safety reasons.) The levels of acidity must be closely monitored in the ethanol-production process so that all the chemical reactions occur properly.
- 3) Bring the mixture to a boil, stirring constantly, for 15 minutes.

While the mash is boiling...

- 4) Prepare the malt. In an Erlenmeyer flask, mix 12g of the prepared ground malt with 100ml of distilled water. (See above for malt sprouting procedures). In this experiment, the class is using a dry-milling technique where the entire mash is fermented, versus the wet-milling method (learned about in the previous lesson) where only the separated starch is fermented. Set this mixture aside.
- 5) Prepare the yeast. In a test tube mix .5g of yeast with 20ml of warm (29C or 85F) water. Add a pinch of sugar and watch for bubbling to show yeast is active. Set aside.
- 6) When mash has boiled 15 minutes, remove it from the heat and cool it for 5 minutes, stirring constantly.
- 7) Under teacher's supervision, set beaker in warm, cool, then ice water to speed up the cooling process. Stir occasionally and check temperature.
- 8) Add malt solution when mash has cooled to 63C (145F). These enzymes will help break down the starch polymers into their sugar particles.
- 9) Allow to cool to 28C (83F), then stir in yeast solution. Yeast is a single-celled fungi that feeds on sugar and causes the fermentation. Since a simple sugar has been obtained, the yeast can now be added. (In the

introductory activity, students *began* at this point with corn syrup (a sugar).)

10) Cover the beaker with a small plastic bag, or transfer the mixture to an Erlenmeyer flask. If available, a pipette rubber hose can be attached to transfer the CO₂ to a different container with water to witness the bubble formation. The teacher should ask for students to make connections to the introductory activity. Make observations of the liquid and of the gas being formed. How is this reaction similar to the introductory experiment? Essentially the same process is going on here: in anaerobic (no oxygen) conditions (the plastic bag, like the balloon, keeps air out), the yeast gets energy from sugar by fermentation. In doing so, what will be produced is ethanol, carbon dioxide, and heat.

Further discussion could also raise the question of what can be done with the carbon dioxide that is produced from the fermentation process. (Carbon dioxide does, in fact, contribute to global warming). In the industry, the CO₂ that's produced is trapped and reused for making dry ice or for making fizz in soda.

11) Let the mixture stand at room temperature for several days. When the bubbling stops, fermentation has ended.

Distillation:

The fermented mash (called "beer") now contains some alcohol along with the non-fermented solids from the corn and yeast cells. This needs to be filtered out ("distilled") to obtain the pure alcohol.

Materials: cloth, beakers, burner set up, flask, stopper, glass tubing, condenser tube, electrical tape, two small graduated cylinders, 4 petri dishes, matches, wood board, lab grade ethanol, safety glasses.

Procedure:

1) Squeeze fermented mash (beer) through a cloth into the Erlenmeyer flask - OR-- Being careful not to disturb the mash, use a pipette to draw off the top clear layer of liquid.

Ask the students to brainstorm what could be done with the leftover mash. If it's not mentioned, the teacher can inform the students that, once dry, the leftovers can be used as a high fat, high protein hog and cattle feed.

2) Transfer liquid or strained beer into a distillation apparatus (for information on how to set up such a contraption, see suggestions at this website: <http://ww2.green-trust.org:8383/ethanol.htm>.)

3) The "beer" should contain about 10% ethanol, so distill into a graduated cylinder the first 10% of the "beer". (Ethanol evaporates first, so you should get mostly ethanol with the first 5ml that are distilled). Ethanol has a low boiling point (78C). When the mix is heated to a temperature a bit higher than this, the ethanol evaporates and is subsequently recaptured as a gas and condensed. In the industry, additional chemicals, redistillation processes, and molecular sieves are used to further purify the ethanol.

4) The teacher should bring this sample around to the students so that they can carefully smell the fuel (by wafting it into their nose). They can compare the smell to "lab grade" ethanol.

5) The teacher should then pour the ethanol fuel into a Pyrex petri dish and light it with a match. A blue flame should be apparent. Compare this to the burning of lab grade ethanol. Ethanol burns cleanly and efficiently with no residue and considerable energy, making it an ideal fuel. The teacher should ask the students what they think might account for the discrepancy between these two fuels (the homemade and the store-bought).

After discussion, the students should know that the ethanol produced in the classroom is not nearly as clean, efficient, and usable as the kind that is industrially created in highly regulated and expensive factories. Every step requires the maintaining of specific acidity levels, pressures, and temperatures. This requires highly developed technologies.

Conclusion

Students should work in their groups to make a poster (with both words and pictures) that includes some of the pros and cons for using ethanol as a fuel in our society. Additional research on

the internet could supplement this investigation (check out various states' agricultural home pages, or energy corporation websites). Examples include: PROS: renewable, alternative energy; cleaner for the air; don't need to drill for oil (or start wars over it), there is a huge rise in the market for flexible-fueled vehicles that are capable of running on more than 85% corn ethanol, etc. CONS: lots of energy is required each step (beginning with planting the corn); there aren't many cars that can use more than a 10% ethanol blend, it's costly, it still produces CO₂ (a greenhouse gas), it takes a long time to refine, etc. Students will have a chance to present their thoughts and findings to the whole class and persuade their peers. The creativity, insight, and thoroughness of this product can be assessed by the teacher as well. **ALTERNATIVE:** Students could debate or write a position paper on this issue: Much energy is required at each step of the way in the production of ethanol beginning with seedbed preparation for planting the corn and ending with that energy needed to transport the ethanol to the place where it is blended with gasoline. The net amount of energy that is actually gained as a result of ethanol production is hotly debated.

Assessment: In addition to assessing lab reports for completeness and organization, documenting accuracy of lab performance while circulating groups, and considering frequency and depth of contribution to discussions, the teacher could:

1) To review the ethanol production process, assign a "step" in the process to each group that they are to creatively and collaboratively *act out* in front of the class. The students need to put these steps in order as well as explain the function. To summarize, the steps are:

1. Mechanically grinding the corn as finely as possible.
2. Stirring while adding water and balancing the pH with sulfuric acid.
3. Adding enzymes and heat to convert starch molecules into complex and then simple sugars.
4. Adding yeast to convert sugars to ethanol through fermentation.
5. Trapping and separating the carbon dioxide.
6. Removing the ethanol from the mash by distillation or evaporation.

2) Students respond to the following questions:

- List the practical everyday products and foods your family uses that are made from corn.
- Refiners separate the corn into its components -- starch, oil, protein and fiber -- and convert them into higher value products. What are the most important refined corn products?
- Corn is a biodegradable, renewable resource? Why is that important?
- How is ethanol produced?

Adaptations: With limited lab space or time, teachers may opt to prepare an exhibit of ethanol production at each stage for students to witness. This would include grinding the corn finely, adding water and balancing the pH, adding enzymes and heat to convert starch molecules into sugars, adding yeast to convert sugars to ethanol through fermentation, trapping and separating the carbon dioxide, removing the ethanol from the mash by distillation or evaporation. In addition, instead of acting, students can opt to draw a picture of the ethanol fermentation steps. More advanced students could be assessed by being shown a picture of one step of the process and asked to identify what is going on. **Extension activities** for students with further interests in corn and its products: **Math:** Students could learn about farmers calculating the maximum value of their acres of corn by calculating area and unit value. They could make decisions about purchasing further

plots of land using proportional reasoning. Students could also graph the use of corn plastics or ethanol use by state or nation to see if there are any discernable trends. They can quantitatively compare the emissions from ethanol fuel to regular petroleum-based gasoline. Students could also use graphs and pie charts to determine the largest corn growing nations in the world. Actually, about 18% of the corn raised in the United States, is sent to other countries. Students will work with charts and calculate figures to learn about world corn production and exports. They will also learn to make the appropriate conversions (from bushels to tons, and U.S. tons to metric tons.)

Social Studies: In general, students can study how the environment affects peoples and shapes societies. Students can learn about the history of corn cultivation and its uses in the past. When did people begin seeing corn as more than just a food product? They can trace the story of ethanol use and corn plastic to several hundreds of years ago. What role did this agricultural product play in migration of populations? How will corn effect technology and industry in the future? What are some of the pros and cons to relying on corn for producing consumer goods? Writing essays, reading journal articles and stories, visiting farms and corn refineries, and talking with scientists can help students begin to answer this question for multiple perspectives and will allow them think critically about human's use of the environment.

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