U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ENERGY EDUCATION AND WORKFORCE DEVELOPMENT

Renewable Energy Plants in Your Gas Tank: From Photosynthesis to Ethanol (Four Activities)

Grades: 5-8, 9-12

Topic: Biomass

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Owner: National Renewable Energy Laboratory

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Renewable Energy Plants in Your Gas Tank: From Photosynthesis to Ethanol

AUTHORS:
Chris Ederer, Eric Benson, Loren Lykins

GRADE LEVEL/SUBJECT:
Secondary Life Science: Grades 7-12
Break-out activities to be used during the study of plants.
- Each lesson is designated with grade level, but can be adapted to any secondary level
- Each lesson takes a variable amount of time (from 1 day to 1 month).

NATIONAL SCIENCE EDUCATION STANDARDS:

CONTENT STANDARD A: **Science as Inquiry**
As a result of activities in grades 9-12, all students should develop:

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

CONTENT STANDARD B: **Physical Science**
As a result of their activities in grades 9-12, all students should develop an understanding of:

- Structure of atoms
- Structures and of properties in matter
- Chemical reactions

CONTENT STANDARD C: **Life Science**
- Understanding of the cell

CONTENT STANDARD E: **Science and Technology**
As a result of their activities in grades 9-12, all students should develop:
- Abilities of technological design
- Understandings about science and technology

CONTENT STANDARD F: **Science in Personal and Social Perspectives**
As a result of activities in grades 9-12, all students should develop as understanding of:

- Natural resources
- Environmental quality
- Science and technology in local, national, and global challenges

CONTENT STANDARD G: **History and Nature of Science**
As a result of their activities in grades 9-12, all students should develop an understanding of:
- Science as a human endeavor
- Nature of scientific knowledge

TEACHER'S OVERVIEW AND BACKGROUND INFORMATION:

With ethanol becoming more prevalent in the media and in gas tanks, it is important for students to know where it comes from. This module uses a series of activities to show how energy and mass are converted from one form to another. It focuses on the conversion of light energy into chemical energy via photosynthesis. It then goes on to show how the chemical energy in plant sugars can be fermented to produce ethanol. Finally, the reasons for using ethanol as a fuel are discussed.

In the initial activity, students use paper chromatography to separate plant pigments from leaves. In this module's second activity the students consider what the source of mass for plants is as they grow. They form hypotheses and design and perform experiments to test them. Next, the students design an experiment to determine which of three different sugars produces the most fermentation products. Once they figure this out they determine what concentration of their "best" sugar would maximize ethanol production and minimize cost. Finally, students discuss the production and use of ethanol as a fuel.

This module follows the path of energy from the sun and photosynthesis to ethanol production. Teachers can stress that in every step of the process energy is neither created nor destroyed. It just changes form. The same can be said of mass.

The module highlights a general method of chemical analysis (Chromatography – Activity One) that is used in more high tech forms to determine the types and concentrations of fermentable sugars produced from cellulosic biomass. Activity two investigates from where plants get their mass. Producing ethanol from cellulose is difficult but does not compete with food production. Activity three in this module will help show students why it is important to measure the types and concentrations of the sugars produced.

PURPOSE OF THE EDUCATION MODULE:

The purpose of this module is to help students understand an important aspect of environmental maintenance: The use of plants for the production of fuel, to acquire 0-net Carbon Dioxide yield.

LEARNING OBJECTIVES:

Students will:

- Discuss the role of plant pigments in photosynthesis.
- Know that photosynthesis produces sugars.
- Discover that, as plants grow, the mass required to do so comes from the air (carbon dioxide).
- Identify ethanol as a product of sugar fermentation and discover that not all sugars produce equal amounts of fermentation products.
- Relate photosynthesis and fermentation to the concept of conservation of energy and mass.
- Discuss the environmental and economic benefits of ethanol as a fuel additive.
- Demonstrate appropriate safe laboratory behavior and techniques
- Document observations and data in an organized appropriate laboratory format
- Analyze and interpret the results of the experimental data and observations
- Communicate their results and conclusions in written lab reports

VOCABULARY: The terminology listed below should be used throughout the unit

Photosynthesis
Chromatography
Chlorophyll
Ethanol
Calorie
Fermentation
Energy
Glucose
Cellulose

MATERIALS*:
Eye protection
1, 2, and 3 liter bottles
Plant seeds (radish, spinach, bean, etc.)
Centigram balance
Dried soil
Pots
Water
Light source

*Included are the materials for a variety of projects. Depending on the time available and your goals for students, it is up to the educator to select necessary resources. Estimated cost and purchase suggestions are listed within the materials section of each activity.

PREPARATORY ACTIVITIES: There is an abundance of information to help the instructor and students understand the concepts associated with this module. Look at the Web resources to get more information.

WEB RESOURCES:

Ethanol

http://www.gcsescience.com/rc16.htm

Chromatography

For an excellent ready to use high school laboratory procedure with handouts and explanations of plant metabolic processes, chromatography, and spectroscopy try:
http://www.chem.purdue.edu/teacher/table_of_contents/UVVUS/UVVIS.Plant Pigments_CH.pdf
The above lab requires the use of petroleum ether and other solvents, therefore it is recommended that this lab be performed outside or under a fume hood.

For information on performing a laboratory investigation suitable for middle school try:
http://www.garden.org/articles/articles.php?q=show&id=1334
This activity requires the use of acetone (nail polish remover.) Once again, consideration must be made for ventilation.

For a virtual lab with many amenities, including a lab quiz, try:
http://www.phschool.com/science/biology_place/labbench/lab4/concepts1.html

For a classroom investigation illustrating the principals of chromatography by separating ink samples in various solvents, in a relatively safe procedure for a middle school setting:
http://library.thinkquest.org/19037/paper_chromatography.html

Biomass
http://www.eia.doe.gov/kids/energyfacts/sources/renewable/biomass.html

Photosynthesis
http://photoscience.la.asu.edu/photosyn/education/learn.html

Fermentation
http://www.umsl.edu/~microbes/pdf/blue.pdf

http://www.pasco.com/experiments/biology/january_2002/home.html

http://www.gcsescience.com/rc16.htm

http://spot.colorado.edu/~kompala/lab2.html

HANDOUTS/Teacher Reference Sheets and Diagrams:
Rubric
KWL Chart
Lab Report Template
Article Summary Template

Before carrying out these activities students should know and understand:

- How to follow safety procedures when performing science experiments
- Should be comfortable with inquiry based learning
- Should have a basic understanding of the life cycles of plants

Plant Pigment Chromatography

Activity #1 – Grades 7-12

(Time: one 45-60 min. class period)

Rationale and Overview:

Separating impure substances into pure substances is one of the basic skills of a chemist. One technique for doing this is chromatography. In 1903, Russian botanist Mikhail Tswett documented how he isolated leaf pigments seen during the fall color change by grinding up leaves in a solvent and pouring the extract through a column of powdered chalk. He noted that various pigments produced concentrated colored bands at unique positions in the chalk column. He studied the individual pigments by carefully removing the chalk column from the containing tube, separating the bands, and extracting the pigments with a solvent.

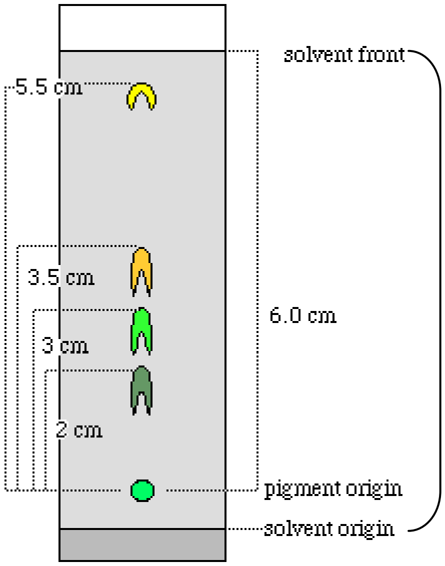
Thus, chromatography works on two principles: solubility (mobile phase) and adsorption (solid phase). The substances in the mixture being analyzed or separated have similar or varying degrees of solubilities in various solvents. Each substance has varying or similar affinities for adsorptive physical and chemical properties of the paper (sorbent). The combination of the solubility and adsorptive properties enable the individual molecular components of a mixture to be separated.

Isolating plant pigments requires solvents that may be problematic in a safe middle school science laboratory classroom. The following is an adaptation of a procedure cited above in the Web Resources for Chromatography.

Objectives:

You will separate the colors out of black ink from a marking pen line on a coffee filter. As water seeps up the filter paper, the molecules of color are carried with them. They can be separated because they are in a mixture rather than being chemically combined. They will attach themselves to the cellulose in the paper, but with differing affinities depending on their chemical nature. Some cling hard while others are only weakly held. Those that are weakly attached to the cellulose travel further up the paper than those with the stronger bond, and they will spread further. Components can be identified by how far they are carried in similar chemical tests, such as chromatography of plant pigments or gel electrophoresis of DNA segments.

Comparisons of the pigments of various materials are made by measuring the distance they are moved on the sorbent by the solvent. The ratio of this distance is termed "RF factor" and is calculated: $RF_{pigment}$= pigment front/solvent front.



Materials:

- Water and rubbing alcohol
- Coffee filter (or filter paper)
- Marking pens (both water soluble and non-water soluble)
- Clear glasses or other containers

Procedure:

1. Cut the coffee filters into strips about 3cm wide.

2. Fill one glass about 2cm full of water and the other about 2cm full of rubbing alcohol.

3. Draw a line across the strip of paper with a marking pen about 4cm from the end of a filter strip. (This may take several times to get a dense concentration of ink on the paper.) Label the end of each strip to identify the kind of marker used. Let them dry.

4. Determine the independent variables.

5. Determine the dependant variables.

6. State the conditions that were controlled.

Obtaining Results:

7. Make a table of measurements for each pigment on each strip.

8. Calculate the RF factor for each pigment.

Conclusion and Post-lab Discussion:

9. What did you see? What colors were actually in the each ink sample?

10. Which colors were carried furthest? *(The lighter colors.)* Which remained lowest? *(The darker colors.)*

11. Which pigment from which ink has the greatest RF? *(Those lightest in color.)* Which pigment from which ink has the least? *(The darker colors.)*

12. What pattern was there to the differences in RF of various pigments?

13. What is happening when the colors move up the paper?

(The molecules of color are being dissolved by the water and carried with the water up the paper.)

14. What causes the colors to separate?

(The different colors have different affinities for clinging to the paper, and those that cling hardest to the cellulose in the paper will stop first, and those that cling the weakest will travel further up the filter paper before stopping.)

Extensions: Create your own controlled experiment. Predict what might happen with different sources of ink, or different solvents like vinegar or cooking oil. Record the results. Set up experiments to test:

Plant Mass

Activity #3: 7-12 grades

Time: 2 ½ - 50 minute class periods

Rationale and Overview:

Where do plants get their mass? We can begin to answer this thought-provoking question if we look at the work of Lavoisier in the 18^{th} century. Lavoisier did careful analytical work with chemical reactions and made this statement based upon his observations: "Nothing is created, either via artificial processes or those of nature, and we can state as a principle that, in every process, there is an equal amount of matter before and after the process; that the quality and the quantity of the elements remain unchanged and that there are only alterations or modifications." The simplification of this statement—matter is not created or destroyed in chemical reactions—is commonly found in science texts. So, where did the 4000 lbs of firewood from a large oak tree get its tremendous amount of mass? Some of the mass comes from water, but even when dried the wood still contains a large amount of mass. At one time, scientists thought that trees got their mass entirely from the soil. This is still a common misconception with people who have not studied the chemical processes that takes place in the leaves of plants. In reality, 96-97% of the dry mass of plants can be related directly to the amount of carbon dioxide processed during photosynthesis. Photosynthesis utilizes CO_2 and H_2O in the presence of sunlight to produce glucose ($C_6H_{12}O_6$) and oxygen gas (O_2). The glucose that is produced is the basis for food chains, and it forms structural polymers like cellulose which forms stems, leaves, and roots. Plants get the bulk of their dry mass from carbon dioxide that is removed from the air. The diagram shows this aspect of the carbon cycle as well as others.

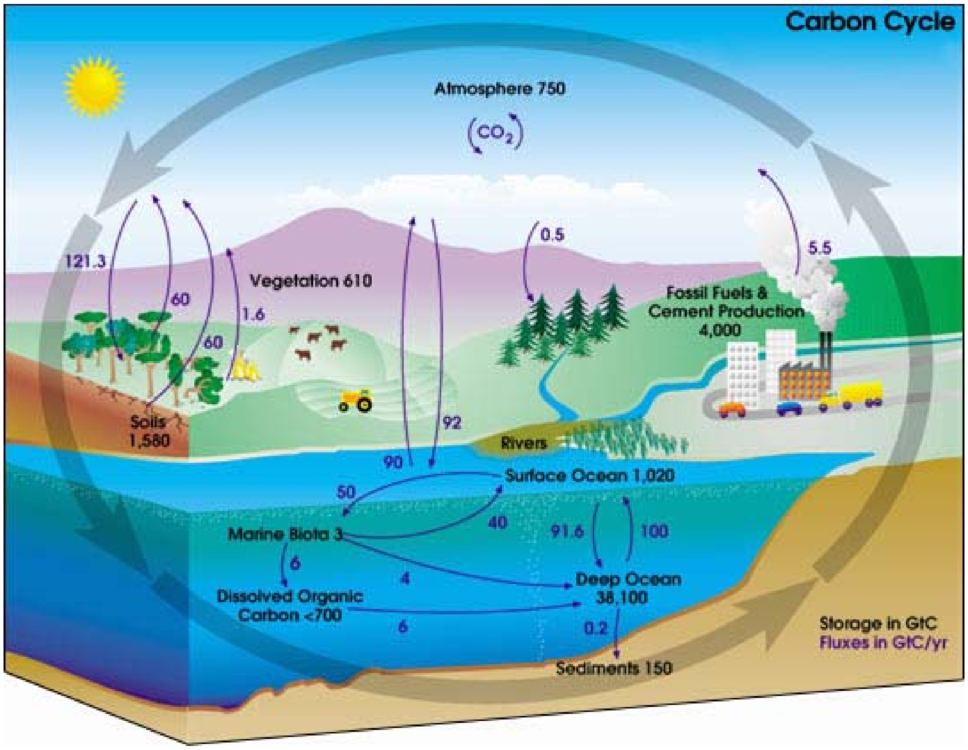


Illustration courtesy of NASA Earth Science Enterprise

Objectives:

Students will:

- Learn about photosynthesis and its contribution not only to the food chain but the mass of plants and the organisms that consume plants.
- Learn to generate a hypothesis and design an experiment to determine the amount of CO_2 removed from the air by growing plants.
- Measure and record mass.
- Graph data.
- Write a report that will explain and summarize the results of the experiment.

Materials:
Plant seeds (radish, spinach, bean, etc.)
Centigram balance
Dried soil
Pots
Water
Light source

Procedure:
The purpose of this lab activity is to design an experiment that will show that plants do not get the bulk of their dry mass from the soil or water but from CO_2 in the air. Students working in groups of two should design their experiment for teacher approval.

A typical experimental design:

1. 5 pots will be obtained, labeled, and their masses recorded.
2. Each pot will be filled with dry soil. The mass of the dry soil for each pot will be determined.
3. Radish seeds will be weighed and their masses recorded.
4. The seeds will be planted, watered, and placed under the light source. (fluorescent grow lamp)
5. After 1 month of growth, the plants will be removed from the pots, and the soil from the roots and pots will be placed in individual drying trays for later weighing.
6. The wet mass of the plants will be recorded.
7. The plants and soil will be allowed to dry for two weeks (an oven may be used to speed up the process)
8. The dry mass of the soil samples and plants will be recorded.
9. Was the mass of the soil considerably different?
10. Where did the plants get their mass?
11. How much CO_2 did the plants remove from the air?

Students should complete a lab report (see Lab write-up template)

Activity #2

Article summary:
Included is an article on biofuel that can be incorporated into the curriculum.

Stored Chemical Energy

Activity #4: Grades 7-12

Activity (Running time: 6 weeks)
Initial Setup Procedure (1 x 45 minute class period):

Rationale and Overview:
Ethanol is produced from the fermentation of sugars. In the United States, the source of the sugars for ethanol used in fuels is corn. Currently only corn kernels are used in the fermentation process, but research continues on using

corn stover as the sugar source. Corn stover is what's left of the corn plant after the kernels have been removed. Corn stover does not include the roots.

Yeast, saccharomyces cerevisiae, is the microorganism used to ferment sugars into ethanol. Yeast easily ferments corn starch, but can't ferment the cellulose and hemicellulose found in stover unless it is pretreated. And even after pretreatment, yeast can't produce as much ethanol using stover because there's much less of the sugar that yeast "likes"—glucose.

This activity first demonstrates yeast fermentation of sucrose (yeast converts the sucrose into its component sugars, glucose and fructose). The activity then has students design their own yeast fermentation experiments. One possible experiment that students may come up with (or that the teacher may suggest) is testing the fermentation rates of yeast in different sugar solutions. This will show students that not all sugars are equally fermentable. This is one of the challenges associated with the fermentation of corn stover. Corn stover contains more xylose than it does glucose. Yeast, unless genetically modified, does not ferment xylose.

Objectives:
Students will:
- Record observations from the activity.
- Explain their observations including the terms fermentation, carbon dioxide, and ethanol.
- Design an experiment to answer their own question about yeast fermentation.
- Generate a hypothesis.
- Perform an experiment to test their hypothesis.
- Write a report that will explain and summarize the results of the experiment.

Materials (per group):
- One half packet of "rapid rise" yeast
- One plastic liter bottle
- One balloon that fits over the mouth of the bottle
- ¼ cup table sugar (sucrose)
- Warm water
- Stirring rod

Procedure:
1. Fill the bottle roughly 2/3 full of warm water.
2. Add sugar to the water in the bottle.
3. Cover bottle and shake until the sugar is dissolved.

4. Add yeast to the sugar solution in the bottle and stir.
5. Put the balloon over the mouth of the bottle.
6. Record observations after one minute, 5 minutes, 10 minutes, 30 minutes, and 24 hours

Student experiments:

After the above activity is performed, students should be ready to design their own experiment. One possible experiment would be to test the ability of yeast to ferment different sugars (if no student group chooses to do this, it could be done as a teacher demonstration). Sugar solutions that could be tested might be table sugar (sucrose = glucose + fructose), corn syrup (fructose), honey (glucose and fructose but not combined to form sucrose), and glucose.

Discussion – why use ethanol and why get it from corn stover?

Ethanol is a renewable energy source often added to gasoline. In this country some gasoline blends contain 10% - 12% ethanol. Other countries, like Brazil, have higher percentages of ethanol in their automotive fuels. The presence of ethanol in gasoline reduces the consumption of this nonrenewable resource. It also reduces pollution as ethanol combustion produces far fewer pollutants than the burning of gasoline. Another advantage of using ethanol for fuel is that it does not increase the level of carbon dioxide in the atmosphere (unlike gasoline). Ethanol comes from plants that absorbed CO_2 from the atmosphere for photosynthesis. The amount of CO_2 released during combustion of ethanol equals the amount used in photosynthesis, so there is no net atmospheric gain.

In the United States, corn is used almost exclusively for the fermentation of sugar into ethanol. As the demand for ethanol as a fuel additive continues to rise, the amount of corn used for fuel will also rise. This raises an ethical issue pitting rich auto owners who want cheaper gas against poor people who need cheaper food. So a different, non-edible source of sugar is needed. One such source is corn stover, although there are many other possible sources. The best source of cellulosic ethanol will be whatever non-edible biomass is in the area.

Attachments

RUBRIC

Lab write-up rubric
30 pts. Clear, concise writing at the appropriate age level
10 pts. Introduction properly written
10 pts. Safety concerns discussed
10 pts. Well written procedure
10 pts. Properly written data (descriptions or tables and graphs)
10 pts. Analysis showing math / calculations
20 pts. Properly stated conclusions

Article Summary rubric
30 pts. Clear, concise writing at appropriate age level
30 pts. Good summary of the article written in the first section
40 pts. Student response involving thought and insight

KWL Chart Group__________

What I Know	What I Want to Know	What I Learned

Lab Write-up Template (replace with appropriate title)

Introduction

This is where you state the problem, sub-problems, hypotheses (one for each sub-problem), and discuss relevant concepts. Try to avoid personal pronouns throughout the write-up (i.e. you, me, I, we, etc.) (Replace this text with your introduction.)

Safety

In this section, safety concerns are discussed with relevant personal protection measures (goggles, etc.) It is unlikely that you will use this section in a virtual science course, and most of the time you will place "not applicable" in this section. In a science class where you are actually manipulating chemicals or specimens, make sure that you describe potential dangers and protective measures. (Replace this text with your safety.)

Procedure

This part of a lab report needs to be written in such a way that another scientist could follow your instructions and exactly replicate your experiment. Be detailed. (Replace this text with your procedure.)

Data

Data can be both qualitative and quantitative. Qualitative data must be described, while quantitative data can be listed in tables or graphed. Graphs produced in Microsoft Excel can be pasted into this section, as well as pictures that show qualitative data. (Replace this text with your data.)

Analysis

Calculations performed on quantitative data are placed in this section. If no calculations are needed, place "not applicable" in this section. (Replace this text with your analysis.)

Conclusions

Discuss data, your interpretation of the data, and its relevance to concepts discussed in the introduction. If there are hypotheses, they should be addressed in this section. (i.e. The data supported hypothesis 1 in that…)

Stay clear of broad statements like "the hypothesis was proven to be true or false." Use words like "supported" or "not supported." (Replace this text with your conclusions.)

Name: John Smith
Date: 5/5/2003
Course: IPC

Article Summary Template (replace with appropriate title)

McCosh, Dan. (1986, July). No-springs, no-shocks suspension. Popular Science. Pp. 60-63. (Replace with appropriate reference info.)

Summary

The author believes active suspension will replace springs and shocks with computers and high-speed hydraulics. The primary benefit of the system is to isolate one suspension characteristic from another. Essentially, MacPherson struts are replaced with hydraulic struts that can react within 3/1000 second, and can cycle up to 1500 times a minute. A computer responds to tiny changes in body and wheel movement by controlling double-acting struts. As well as sensing bumps, the system reads the forces acting on the car body preventing it from banking to the outside of a curve. The idea of active suspension is credited to Britain's great interest in its application. American auto manufacturers have characterized the system as expensive, noisy, and consuming power. However, it may appear on some "expensive" U.S. automobiles by 1990. **(Replace with your summary of the article.)**

Reaction

This article has good appeal for automobile enthusiasts who want to keep abreast of the latest technology. The reporting of this innovative suspension system was very consistent and well documented by the use of interviews. Several pictures of the system components were shown as well as a pictorial schematic of the complete suspension system. Upon reading this article, anyone would have a good working knowledge of the computer controlled suspension. **(Replace with your reaction and thoughts related to the article.)**

Do not change margins or fonts. (one page maximum)

Technology Review (Cambridge, Mass.), April 2005 v108 i4 p44(1)

Brazil: the giant of South America is weaning itself from oil and bringing the Net to the poor. (World Changing Ideas)
Laura Somoggi.

BRAZIL'S TWO TOP priorities are to reduce dependence on imported energy sources and to bring digital technologies to the vast majority of the country's 180 million people who cannot now afford them.

In energy, the center of the greatest activity is biodiesel, a fuel made from the oil of seeds such as soybeans, castor beans, and cottonseed. Biodiesel could become an attractive, domestically produced alternative to petroleum-based fuels. Brazil has enacted a law requiring diesel oil sold in the country to be 2 percent biodiesel by 2008 and 5 percent biodiesel by 2013. Because the country has huge amounts of land that is unsuited for food crops but that can easily grow oil seeds, "Brazil can become a global biodiesel power," says Maria das Gracas Foster, secretary of oil, gas, and renewable energy at the Ministry of Mines and Energy.

The consequences could be considerable. Brazil now imports 15 percent of the 37 billion liters of diesel it consumes annually. Large-scale use of biodiesel fuels would allow it to all but discontinue those imports and would create jobs in needy farming communities. There are also significant environmental benefits: substituting biodiesel for petroleum-based fuels reduces emissions of unburned hydrocarbons, carbon monoxide, sulfates, sulfur, and other pollutants.

Another alternative fuel that could help Brazil reduce its oil dependence is ethanol from sugarcane. A study conducted by Roberto Giannetti da Fonseca, a specialist in foreign trade, found that Brazil is the producer of fuel ethanol in the world, with an export potential of up to 10 billion liters per year for about $2 billion in revenue. Because of its extensive use of ethanol fuel, Brazil has developed the flex-fuel car, which features a combustion engine that can burn ethanol, gasoline, or any combination of both. Volkswagen introduced the car in Brazil in March 2003. Last year, sales of new flex-fuel or ethanol vehicles amounted to 26 percent of overall car sales. According to Booz Allen estimates, that fraction could rise to 40 percent within the next two years, and Brazil could begin to export the flex-fuel technology. "Thanks to this technology, Brazil will be dependent on neither oil nor ethanol," says Fernando Reinach, executive director of Votorantim Novos Negocios, the venture capital subsidiary of the Votorantimi Group, a major Brazilian industrial conglomerate.

While reducing energy dependence will help the Brazilian economy in the long run, another technological initiative is starting to have more-immediate consequences. Only about 12 percent of Brazilians own PCs. The last few years have seen a number of projects designed to make computer technology accessible to large numbers of Brazilians for whom it was previously unaffordable. The Committee for Democracy in Information Technology (CDI), for example, collects PCs in good working condition that businesses have discarded as obsolete and ships them to information-technology training centers. More than 900 schools in Brazil and abroad have benefited from this program. In 2001 a new project was born. one to provide Brazilian who don't own PCs with a sort of virtual machine--as long as they have access to a publicly shared computer terminal. The project is called Computador de R$1.00, or Computers for 1 Real--the equivalent of about 40 cents. That's the price of a recordable CD that stores personal data and settings that customize the appearance of a computer screen. The user simply inserts the disc into the CD drive of a computer at a school, a public library, or even a shopping mall. The system reads the disc and presents a personalized computing environment, complete with application software and access to additional content over the Internet. The system is already in place in pilot form in community centers and schools in cities such as Silo Paulo, Brasilia, and Campinas; hundreds of Brazilian schools will soon begin offering system discs to their students. Project collaborators include Siemens, T-Systems, Brasil Telecom, Brasilia University, publisher Editora Abril, and Brazilian infotech firm Samurai.

One application of information technology in which Brazil is taking a leading role is voting machines. In Brazil's 2000 local elections, for the first time, all 5,559 of its municipal districts offered voters the chance to cast their ballots electronically. Most polling places used a simple, portable electronic voting machine. To boost confidence in the system's reliability, Brazilian law guarantees that all political parties can examine the machine's software before the election, says Paulo Cesar Bhering Camarao, information technology secretary of the Supreme Electoral Court. A digital signature extracted from the software caw then be used to verify that the used on election day is the same one examined previously.