On the Road to Future Fuels and Vehicles

NREL's research helps move the nation toward energy independence

The total price that Americans pay for gasoline and diesel fuel isn't the one shown on the pump. Because we import about 60% of our crude oil, we are vulnerable to price fluctuations, disruptions in supplies, and political instabilities that affect our entire economy. We also pay a price in terms of our environment and health. For example, more than 30% of all U.S. air emissions come from burning traditional fossil fuels for transportation.

At least 240 million U.S. vehicles—one for 80% of all the men, women, and children in the country—were registered in 2004, according to Department of Transportation statistics. It takes a lot of fuel to keep all those wheels moving. The Department of Energy reports that the average American household uses more than 1,000 gallons of gasoline each year. Gasoline makes up nearly half of the 20 million barrels of petroleum products that we consume each day, to cover more than 7 billion daily miles.

Addressing these issues, in February 2006, President George W. Bush announced the Advanced Energy Initiative. This national initiative calls for greater reliance on domestic energy sources, including solar and wind energy, to power our homes and offices. And it increases funds for research and development (R&D) in advanced batteries for hybrid vehicles, electric cars, and hydrogen-powered vehicles, as well as alternative transportation fuels, particularly ethanol.

With the support of the Department of Energy's Office of Energy Efficiency and Renewable Energy, and in partnership with both public and private organizations, NREL's scientists and engineers are assisting in this effort by conducting R&D in innovative fuel and vehicle technologies. These technologies will help to reduce our nation's dependence on imports, enhance our energy security, and improve the quality of our air.

Here, we review where we are now, in terms of R&D and market readiness, as well as where we plan to be in 5 to 10 years and where we want to be in 20 years. This work has been, and will be, key to developing tomorrow's fuel and vehicle technologies. These technologies include advanced hybrid electric vehicles, plug-in hybrids, biodiesel and other biofuels, ethanol produced from cellulosic biomass, advanced batteries, hydrogen fuels, fuel cells, and more.

Where We Are Now

Today, ethanol, biodiesel, flexible-fuel vehicles, and hybrid-electric vehicles are all available in some form, but in limited quantities, in the United States. Since the Energy Policy Act of 2005 establishes a renewable-fuels standard requiring total U.S. transportation fuel sales in 2012 to include 7.5 billion gallons of renewable fuel, we should see steady increases in the use of biofuels and the vehicles that run on them.

Today, more than 30% of U.S. gasoline is E10—gasoline blended with 10% ethanol. About 90% of the U.S.-produced ethanol in this blend is made from the starch and simple sugars in corn. The availability of E10 depends on local prices and air-quality regulations, however.

Flexible-fuel vehicles. In some parts of the country, particularly the Midwest, consumers can purchase E85—an ethanol blend containing 15% gasoline. But E85 can be used only in "FFVs"—flexible-fuel vehicles that run on either gasoline or ethanol blends. At present, U.S. automakers manufacture flexible-fuel versions of several popular models, such as the Ford F150 truck and the Chevrolet Suburban sport utility vehicle. About 4½ million to 5 million FFVs are estimated to be on the road today.

However, many FFV owners are unaware that they have one. A recent survey of FFV owners by an ethanol producer found that 70% didn't know they owned a vehicle that can run on E85. Those who do know might wonder where they can purchase this fuel; less than 600 service stations offered E85 in January 2006. A tax credit in the Energy Policy Act of 2005 provides for developing an alternative fuel infrastructure, and this could help increase that number. And at least one automaker, GM, has stepped up public information efforts regarding FFVs and E85.

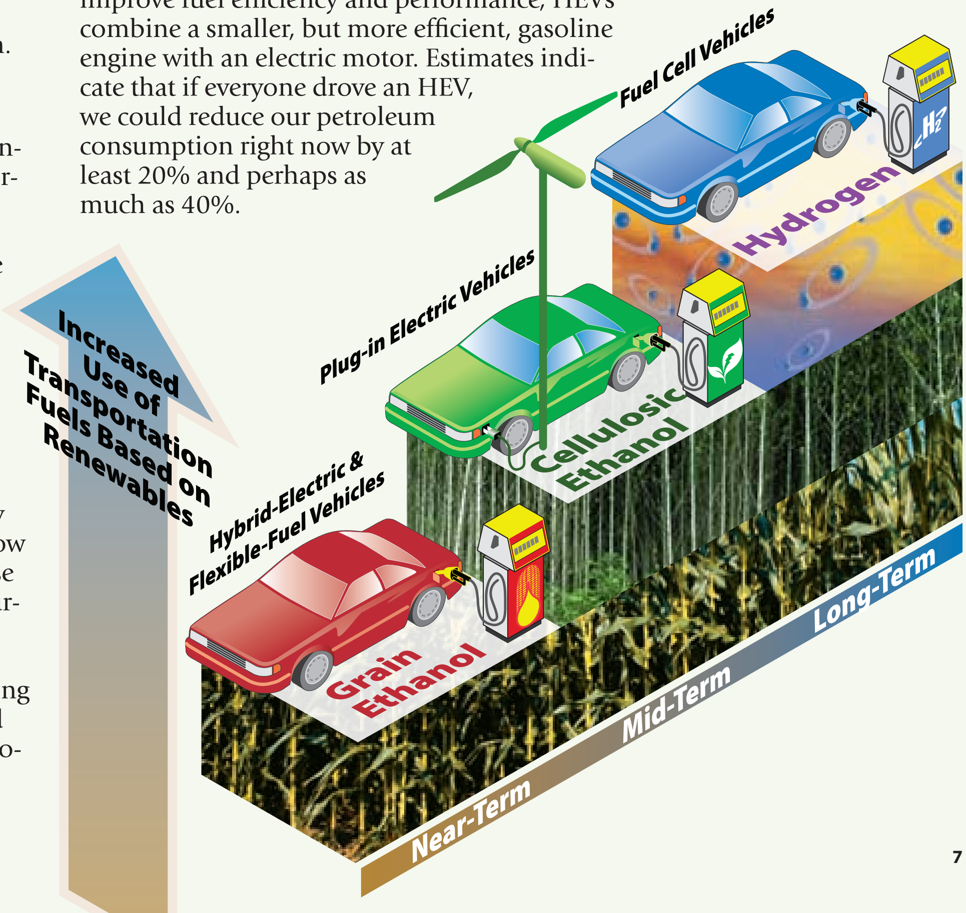
The Alternative Fuels Data Center. NREL is helping to expand the market for alternative fuels and vehicles through the Alternative Fuels Data Center, or AFDC. Supported by the Department of Energy's Office of Energy Efficiency and Renewable Energy and housed at NREL for more than a decade, the AFDC is a searchable electronic library of technical data, publications, and information on advanced and alternative fuels and vehicles (see www.eere.energy.gov/afdc). It also contains information about financial incentives, regulations, fuel performance, emissions, funding and training resources, industry contacts, and updates on advanced vehicles.

In addition, the AFDC Vehicle Buyer's Guide helps both fleet managers and consumers evaluate various fuel and vehicle options. An Alternative Fuel Station Locator provides maps showing U.S. fueling stations. And additional databases provide useful technical data—for example, on vehicle emissions and performance.

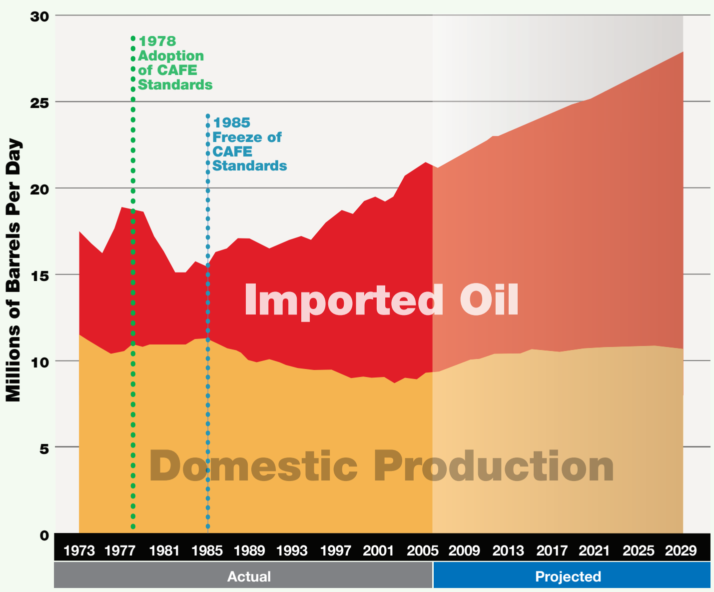
Hybrid-electric vehicles. Though they are still new kids on the road, hybrid-electric vehicles—HEVs—are becoming increasingly popular; about 1.3% of light vehicles sales in 2005 were HEVs. To improve fuel efficiency and performance, HEVs combine a smaller, but more efficient, gasoline engine with an electric motor. Estimates indicate that if everyone drove an HEV, we could reduce our petroleum consumption right now by at least 20% and perhaps as much as 40%.

PIX13531/Charles Bensinger, and Renewable Energy Partners of New Mexico

Options for reducing our use of imported oil are available to consumers now. Diesel vehicles can use 20% biodiesel. Flexible-fuel vehicles can use 85% ethanol. And 10% ethanol is widely used for fuel-efficient hybrid-electric or any regular vehicle. NREL is working to improve the competitiveness of these current alternatives and to develop new technologies for the future.



U.S. Dependence on Foreign Oil



Source: Historic data from Energy Information Administration (EIA), Monthly Energy Review 2006, Table 3.1A; projections from EIA Annual Energy Outlook 2006, Table 11.

Working with major U.S. automakers, NREL researchers have been contributing to the development of HEVs for more than a decade. Today, they are still investigating ways to improve the performance of HEV components and working with industry to put those improvements into practice.

One key to making HEVs more practical is to incorporate low-cost, integrated power electronics. NREL, other national laboratories, DOE, and industry are working on advanced components that condition the electrical signal between the power generation unit (a battery or fuel cell) and the electric motor.

Heavy-duty vehicles are prime subjects for R&D, because they consume much more fuel per vehicle than passenger cars do. Working with industry, NREL is developing advanced hybrid components and systems that could increase the fuel efficiency of heavy trucks as much as 100%.

Biodiesel. For diesel-powered vehicles, one renewable fuel option is B20—a blend consisting of 20% fatty acid methyl ester (known as biodiesel) and 80% petroleum diesel fuel. Biodiesel can be made from any animal or vegetable fat or oil and used in just about any diesel vehicle. It can reduce environmental emissions dramatically, depending on the blend. U.S. biodiesel is largely produced from soybean oil and recycled restaurant cooking oil.

Staff at NREL have been working to reduce the technical barriers that stand in the way of producing biodiesel and using it more widely. They also test biodiesel products in engines supplied by various industry partners. Their work will help to make biodiesel more cost-competitive, reliable, and plentiful.

Where We Should Be in 5 to 10 Years

Mid-term options such as cellulose-based ethanol and "plug-in" hybrid-electric vehicles are technologies in the latter stages of development, but they are still too expensive to compete in the marketplace. Therefore, NREL's researchers and engineers are working to improve these technologies so they can be competitive and widely available.

Cellulosic ethanol. The starchy material in corn kernels now used to produce most of our ethanol is only a small fraction of the biomass—the plant-based materials and waste products—that could be used. Two other components of plants, cellulose and hemicellulose, are also made of sugars, but those sugars are linked in long polymer chains that are not easy to convert to ethanol. Advanced biomass conversion technologies break down the polymer chains into their component sugars and then ferment them into alcohol to produce cellulosic ethanol.

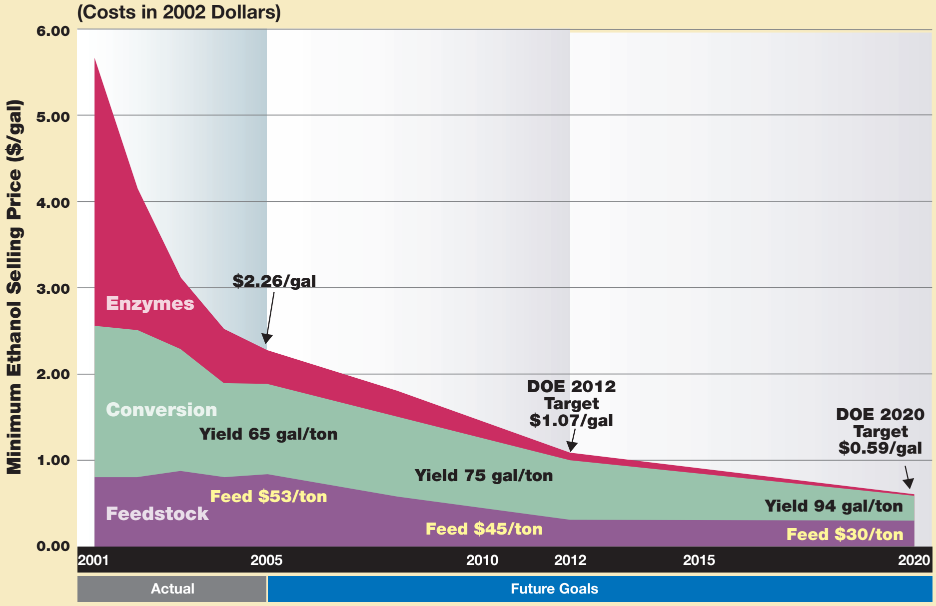
This technology thus turns ordinary, low-value plant materials—such as corn stalks, sawdust, wood chips, wastepaper, and fast-growing trees and grasses—into ethanol and other valuable fuels and chemicals. Cellulosic ethanol could do much to reduce our dependence on imported oil and curb U.S. greenhouse gas emissions. The technology works—but it's still too expensive. So, national laboratories and private-sector groups alike are developing more cost-effective production methods.

For many years, NREL has been developing technologies that produce ethanol and other valuable fuels and chemicals from cellulosic biomass. Our researchers have conducted much of the basic research underpinning a process in which a dilute acid is used to break down hemicellulose. In a step known as enzymatic hydrolysis, enzymes break cellulose down into its component sugars. While we focused on the process, our research partners made great strides in reducing the cost of the enzymes. Four years ago, these enzymes were too expensive to be used in a cellulosic ethanol process. Today, enzymatic hydrolysis is the lowest cost option for hydrolyzing cellulose to glucose.

NREL researchers are also leading the development of better pretreatment methods, which use dilute acid at elevated temperatures and pressures to break down hemicellulose into component sugars. And they engineered one of only three organisms to date that can co-ferment cellulosic and hemicellulosic sugars.

In NREL's one-ton-per-day feedstock pilot plant, researchers continue to partner with companies in the vanguard of this emerging industry to validate new biomass-to-ethanol technologies. They still need to be simpler and less expensive; for example, the capital equipment and sophisticated processing steps required are costly. So NREL is

Cost of Ethanol from Cellulosic Biomass



Source: U.S. Department of Energy, Biomass Program data

NREL continues to investigate technologies that allow us to produce ethanol economically from corn stover—the husks, leaves, and stalks that today are left behind in the field after the corn is harvested. This feedstock is both high in volume and low in cost. However, capital equipment and ethanol processing costs are still too high for the technology to compete with gasoline and with ethanol made from corn kernels. Though NREL has made great progress in reducing the cost of cellulosic ethanol technology, some key hurdles remain to be overcome. NREL's analysts calculate that a price of $2.26 per gallon is needed to allow industry to build a profitable plant today. And a price of $1.07 per gallon is needed for large-scale market penetration—a goal we hope to reach by 2012.

working to change this. When all process design targets are met and ethanol can be produced for a little more than $1.00 per gallon, cellulosic ethanol will be competitive with ethanol from starch and probably even with gasoline.

NREL researchers and their partners have received several technology awards for novel biomass conversion methods. And they are working to enable industry to produce fuels, chemicals, and other products in biorefineries that would manufacture a variety of products from biomass—much as today's oil refineries and petrochemical plants do from petroleum.

Other mid-term biofuels. NREL researchers have helped to develop processes for gasifying or liquefying biomass by heating it with little or no oxygen. Using the Fischer-Tropsch conversion process and others, they can catalytically convert the resulting synthesis gas to diesel substitutes and other fuels. NREL has also partnered with industry to explore whether a bio-oil produced through the pyrolysis of biomass could be a useful intermediate for producing clean biofuels. Several small biomass gasification and pyrolysis plants are already up and running.

In the biorefineries of the future, selected sugars and intermediates would be made into high-value products for various markets. The remaining sugars would be fermented to ethanol fuel. The lignin in plants might also be gasified or pyrolyzed and converted to fuels and chemicals.

NREL scientists and their industrial partners are also evaluating an option known as "green diesel." Biodiesel contains molecules

Ethanol from Corn Kernels: Is It an Effective Use of the Resource?

Critics of corn-based ethanol often say that it takes more energy to produce the ethanol than we get from the resulting fuel. But official studies demonstrate just the opposite. The efficiency of both corn farming and ethanol production has dramatically increased over the years. The latest U.S. Department of Agriculture (USDA) study calculates a net energy balance of 1.67 for ethanol production; that is, for every unit of energy that went into growing the corn and turning it into ethanol in 2001, we got back about two-thirds more energy in the form of automotive fuel and animal feed.

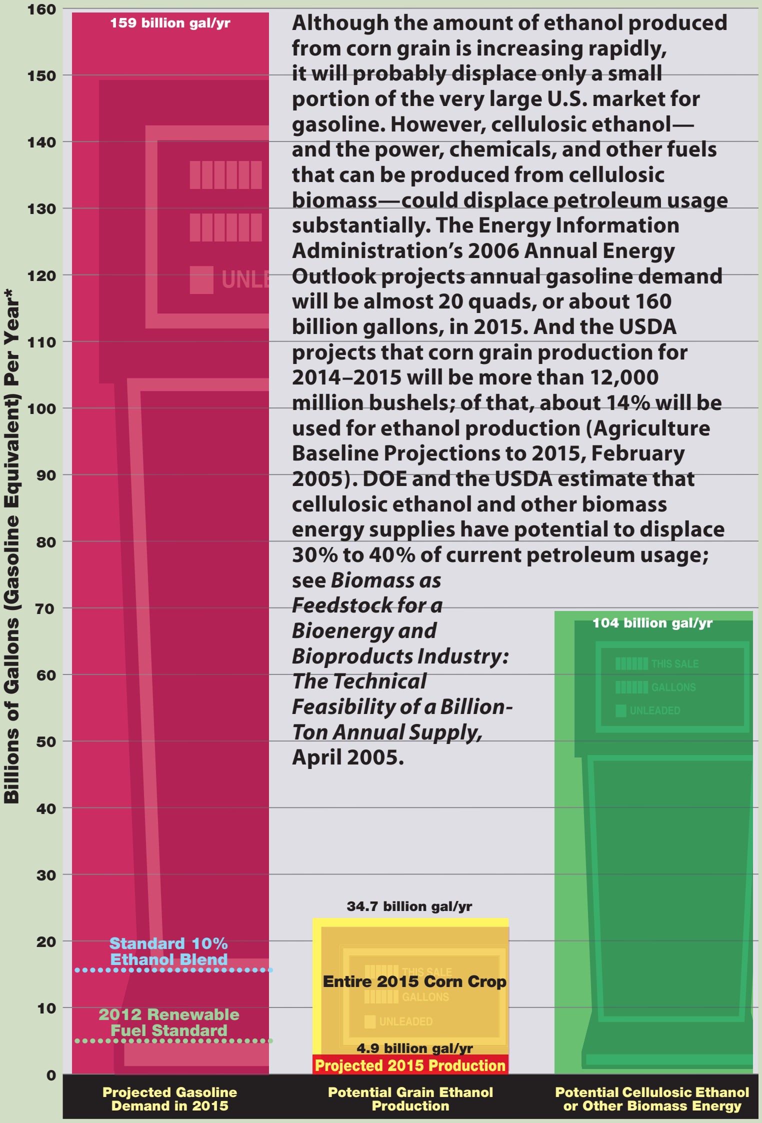
Even if that net energy balance were less than one, ethanol production and use still displaces oil imports with domestic nonpetroleum energy, which is a major plus in terms of reducing our dependence on imported fuel. On the basis of liquid fuels alone, the USDA calculated a net balance of 6.34. It is important to note that the energy in ethanol totally replaces gasoline energy, and relatively little petroleum product is used to produce it.

It is true that modern corn farming and ethanol production are both energy-intensive, and that the "net energy" gain of some early ethanol plants was relatively modest. But allegations about a negative net energy balance seem to be based either on using old data or failing to take into account the considerable value of the animal feed co-products of ethanol production.

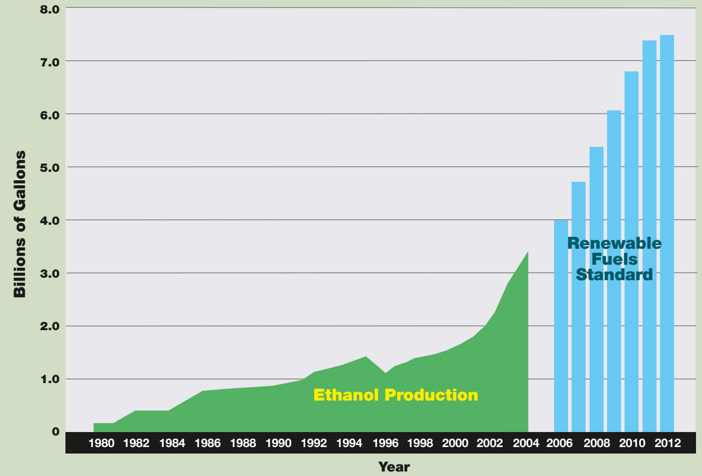
Animal feed co-products are a critical part of any effectiveness analysis because they are a major part of the economics of ethanol production. Corn, the largest U.S. crop, is used primarily for high-starch animal feed. Ethanol production uses up most of the starch from the kernels, but leaves the protein and fiber, so ethanol co-products are very high in protein and therefore are high-value animal feeds.

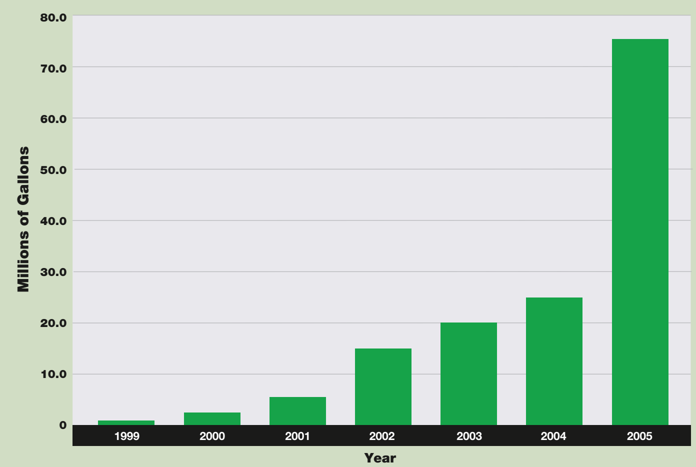
Can Biofuels Displace Gasoline?

Although the amount of ethanol produced from corn grain is increasing rapidly, it will probably displace only a small portion of the very large U.S. market for gasoline. However, cellulosic ethanol—and the power, chemicals, and other fuels that can be produced from cellulosic biomass—could displace petroleum usage substantially. The Energy Information Administration's 2006 Annual Energy Outlook projects annual gasoline demand will be almost 20 quads, or about 160 billion gallons, in 2015. And the USDA projects that corn grain production for 2014–2015 will be more than 12,000 million bushels; of that, about 14% will be used for ethanol production (Agriculture Baseline Projections to 2015, February 2005). DOE and the USDA estimate that cellulosic ethanol and other biomass energy supplies have potential to displace 30% to 40% of current petroleum usage; see *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, April 2005.



*The right- and left-hand scales are different because ethanol has only two-thirds as much energy per gallon as gasoline. For example, 90 billion gallons of ethanol is equivalent--in energy terms--to 60 billion gallons of gasoline.





produced by trans-esterifying triglycerides with methanol. Green diesel consists of paraffin molecules produced by hydrogenating triglycerides by means of a conventional petroleum refining process. Green diesel has a very high cetane number, so it ignites fairly quickly after injection, and a low pour point—the lowest temperature at which a fuel will pour. Thus, it is a high-quality diesel fuel and is totally compatible with petroleum diesel.

Plug-in hybrids. In addition to producing transportation fuels from biomass, we can also put electricity to work to reduce our petroleum usage. Electric vehicles are clean and quiet, and there are already some vehicle recharging stations around the country. This vehicle technology could be fully renewable if the recharging stations provided electricity generated by wind, solar, and other renewable energy technologies.

Today's HEVs do not depend on an external means of recharging their batteries. NREL is working to move HEV technology a step further by developing hybrids that can be plugged in to store electricity for later use. Adding extra batteries to an HEV and a means to plug them in, we would drive most of a typical day on domestic electricity and still have fuel in the tank for longer trips.

Today's batteries are heavy and expensive, however. So, NREL is researching advanced drive trains and other vehicle components—such as batteries—that can be used in conventional, hybrid-electric, and plug-in hybrid vehicles. Advances in batteries and other energy-storage technologies are essential to the success of plug-in hybrids. NREL is also exploring ways to make plug-ins reversible, so that excess power stored in the vehicle would go back into the utility grid, to the owner's credit.

Where We Need to Be in 20 Years

Taking all this another step further, NREL foresees the emergence of "renewable communities" that would feature plug-in hybrids, zero-energy homes, and various renewable energy technologies. They might not be a reality now, but they are a part of our vision for the future.

We support the Department of Energy's "30 by 30" goal, which means that ethanol will make up at least 30% of our nation's transportation fuels by 2030. Research in other long-term technology options, such as renewable-based hydrogen fuel and fuel cells, is also important, especially in terms of the basic science underlying those technologies. Hydrogen fuel cells for transportation and hydrogen vehicles are so promising that California and some states on the Atlantic Coast are setting up prototype hydrogen fueling stations to test new technologies as they develop.

Hydrogen production. Producing hydrogen by steam-reforming natural gas, today's most economical method, would increase our reliance on an increasingly scarce fossil fuel. So, NREL is pursuing a renewable option: gasifying biomass and reforming the resulting syngas to hydrogen through a water-gas shift reaction.

NREL researchers are also exploring the use of cost-effective solar, wind, and other renewable technologies to electrolyze water to produce hydrogen. And they are pursuing both photoelectrochemical and photobiological technologies that could produce hydrogen directly.

The photoelectrochemical approach integrates elements of a photovoltaic cell with elements of an electrolyzer, so that the absorption of light energy triggers the splitting of a water molecule in an aqueous electrolyte. Because aqueous photovoltaic cells and electrolysis share anode, cathode, and electrolyte components, this approach is potentially much more efficient than the separate steps of electricity generation and electrolysis.

The photobiological approach takes advantage of the fact that certain microorganisms—such as green algae—naturally split water to produce hydrogen as a way to dissipate the energy they do not need in certain circumstances. Researchers have been creating new genetic forms of the microorganisms that can sustain hydrogen production in the presence of oxygen. One system uses a metabolic switch (sulfur deprivation) to cycle algal cells between a photosynthetic growth phase and a hydrogen production phase.

Fuel-cell research. Fuel cells could revolutionize the way we power our nation, providing clean, more efficient alternatives to burning fossil fuels. However, many challenges must be overcome before fuel cells will be competitive in the marketplace. Therefore, NREL's work focuses on

Where Will the Biomass Come From?

We are not likely to be able to replace all our petroleum-based fuels and chemicals with biomass-derived products. However, it is a good idea to set some goals for the contribution biomass can make to meet future petroleum demand.

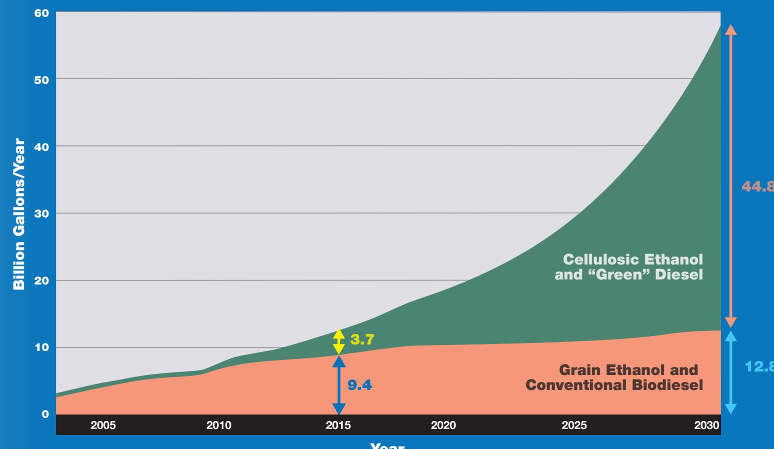
The Biomass R&D Technical Advisory Committee to the Secretaries of Energy and Agriculture has stated that biomass could supply 5% of current U.S. power needs, 20% of transportation fuel requirements, and 25% of chemical needs by 2030 (*Vision for Bioenergy and Biobased Products in the United States*, October 2002). This would displace 30% of our petroleum use and require about a billion tons of biomass per year to meet current U.S. consumption levels.

A subsequent joint DOE-USDA study headed by Oak Ridge National Laboratory that included contributions from NREL and others was conducted to determine whether that goal is feasible. The study found that forestlands and agricultural lands—the two largest sources of biomass—could produce the following annual tonnages by 2030:

Forestlands		
Fuelwood harvest from forests		52
Residues from wood processing & pulp & paper mills		145
Urban wood residues		47
Residues from logging and site-clearing operations		64
Forest thinnings to reduce fire hazards		60
Forestlands subtotal	**368**	
Agricultural Lands		
Annual crop residues		428
Perennial dedicated energy crops		377
Crop grains used for biofuels		87
Manures and miscellaneous		106
Agricultural lands subtotal	**998**	
Total production in 2030 (in million dry tons of biomass)		**1,366**

The study concludes that enough biomass would be available in 2030 to meet about 40% of our current petroleum use. Business-as-usual projections for petroleum use predict a substantial increase. But much more efficient vehicles and the use of electricity rather than liquid fuels (for example, for plug-in electric hybrids) could reduce the need for petroleum dramatically. Key assumptions in the study included these: crop yields will increase by 50% by 2030; cropland will switch to no-till management; 55 million acres will be converted to dedicated energy crops; crop and residue harvesting technology will improve; and environmentally sensitive lands and forestlands not accessible by road would be excluded. (See *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, April 2005).

Required Growth of Advanced Renewable Fuels to Supply 30% of Current U.S. Gasoline Demand by 2030



PIX14682/Dean Armstrong

NREL's Bill Kramer shows a power inverter and a new cooling system that NREL developed and is testing in its new Electrical Systems Laboratory.

New NREL Facilities Provide Key Tools for Studying Surfaces and Heat Flow

Two new NREL laboratories provide researchers with important resources they can use to improve fuel and vehicle technologies. The state-of-the-art electron microscopes in the recently opened Biomass Surface Characterization Laboratory (BSCL) are powerful tools for understanding the core mechanisms underlying biomass conversion processes. The new Electrical Systems Laboratory (ESL) provides the essential capabilities needed to improve the efficiency and thermal management of power electronics for hybrid-electric, fuel-cell, and other advanced vehicles.

Surface analysis is key to understanding both biological and chemical reactions. These reactions are basically a function of the way a catalyst interacts with a substrate (for example, acid and water acting on hemicellulose or enzymatic proteins acting on cellulose). It takes sophisticated equipment to determine the actual shape of a chemical or protein and how it interacts with biomass. The new BSCL provides NREL biomass researchers with some of the best equipment available, including scanning-electron, atomic-force, transmission-electron, near-field-scanning-optical, and confocal microscopes.

For vehicle efficiency, it is important to understand heat flow and performance under anticipated uses. The ESL's capabilities start with a 125-kilowatt bidirectional power supply. This allows researchers to simulate the way electricity flows from a hybrid vehicle's battery to its motor and back, both to assess performance under various drive cycles and to represent actual heat-flow situations. A high-heat-flux test loop allows heat flow to be assessed within various power electronics components. Researchers are already using it to develop and test innovative cooling systems for the power inverters needed to convert the DC current of a battery to the AC required by the motor. Ultracapacitors are also being studied; they have less total power storage capability than batteries, but can deliver much more power for a short time and could boost the efficiency of certain types of vehicles.

improving the performance and cost effectiveness of fuel cell systems, subsystems, and components. Specific research areas include system analysis and component research.

Fuel cells are rather complex, so innovative analysis tools are needed to design them. NREL is using a variety of tools to identify critical design issues for fuel cell vehicles and systems. We work with industry to share and apply robust design tools and techniques to address such issues as durability, cost, and efficiency.

Simulation tools. Much of NREL's research in advanced vehicles makes use of computer simulations of vehicle technologies to model, evaluate, and optimize them. A basic problem underlying our dependence on imported oil is that today's cars and trucks are not very efficient. Even a hybrid-electric vehicle uses less than one-fifth of the energy—fossil or renewable—that goes into it. Because several different configurations for hybrid-electric and fuel-cell vehicles are possible, and numerous alternative technologies could be used in key vehicle components, computer modeling is critically important.

Using NREL-created models such as ADVISOR (Advanced Vehicle Simulator), which is now commercially available, we can simulate potential vehicle technologies and combinations of technologies in days or weeks, rather than the months or years it takes to build and test prototypes. Using these computer tools, we can advise automakers, equipment providers, other government programs, and our own researchers on the most promising avenues to pursue to reduce the environmental impacts of vehicles and improve their efficiency and performance.

NREL has also developed a unique thermal comfort manikin known as ADAM (the Advanced Automotive Manikin), which is designed to help the automotive industry design smaller, more efficient climate-control systems in vehicles.

The ultimate goal of all this research and development is to enable U.S. industry to produce advanced, low-emission, economically competitive fuels and vehicles that will meet our future transportation and environmental needs. Pursuing all options, we are on the way to greater energy independence.

For More Information

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Web sites:

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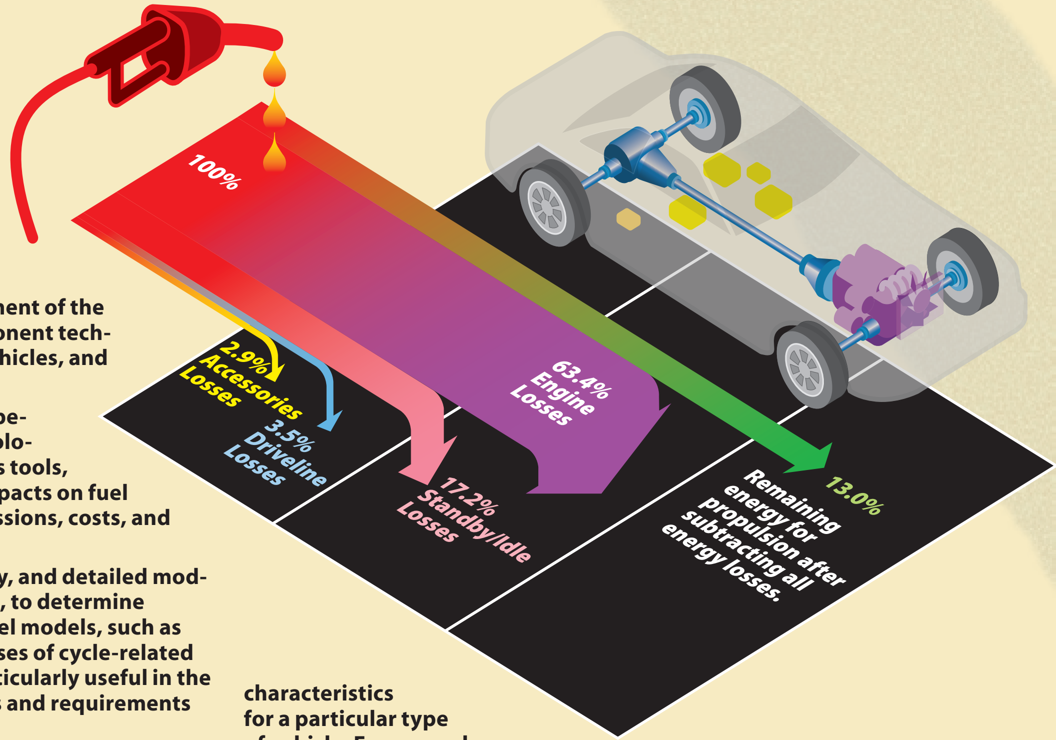
- National Renewable Energy Laboratory Advanced Vehicles and Fuels Research, www.nrel.gov/vehiclesandfuels/
- U.S. Department of Energy, Energy Efficiency and Renewable Energy Alternative Fuels Data Center, www.eere.energy.gov/afdc/
- U.S. Department of Energy, Energy Efficiency and Renewable Energy Biomass Program, www.eere.energy.gov/biomass/index.html, www.eere.energy.gov/biomass/publications.html
- U.S. Department of Energy, Energy Efficiency and Renewable Energy FreedomCAR and Vehicle Technologies Program, www.eere.energy.gov/vehiclesandfuels/

Sophisticated Modeling Capabilities for Advanced Vehicles R&D



In developing a new vehicle, engineers can shave years off the process by using simulations that clearly show the designs and components that will (or won't) achieve their performance goals. At NREL, vehicle systems analyses help to guide the development of the most promising advanced vehicle and component technologies, such as plug-in hybrids, fuel cell vehicles, and advanced storage technologies.

NREL's expert analysts have considerable experience in evaluating advanced vehicle technologies. Using computer simulation and analysis tools, they evaluate new technologies and their impacts on fuel economy, vehicle performance, exhaust emissions, costs, and market potential.

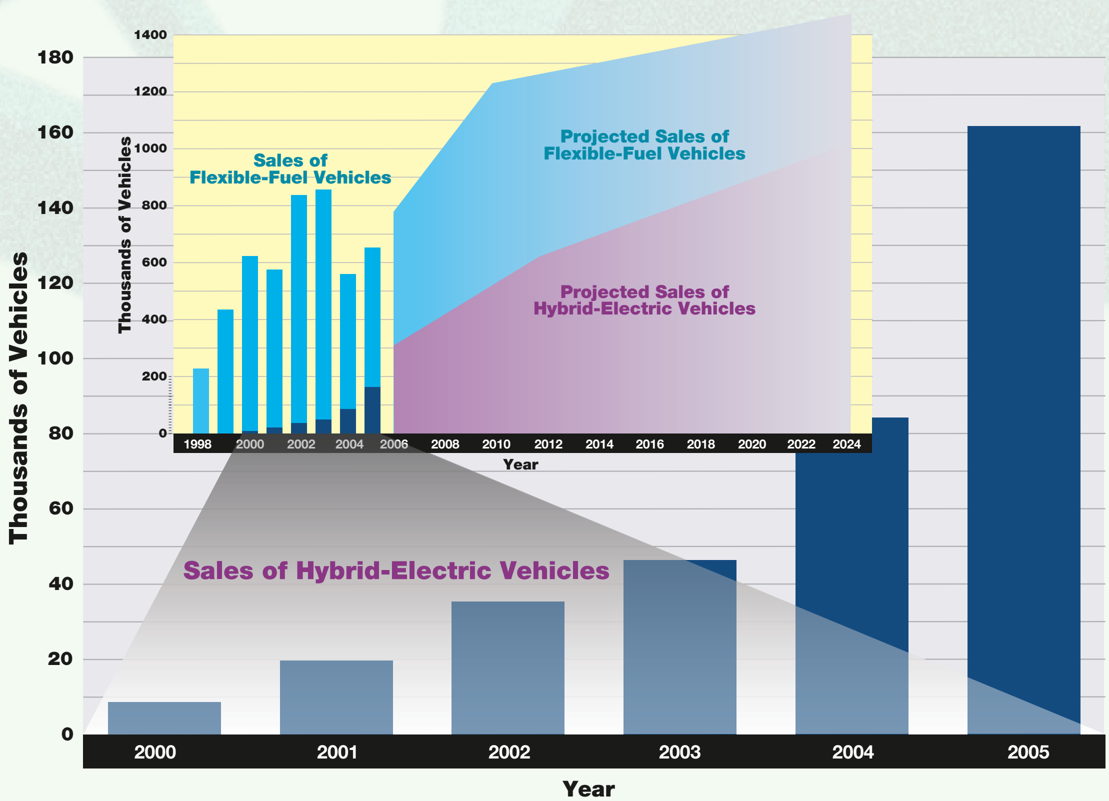
For example, they use high-level, exploratory, and detailed modeling tools, as well as robust design methods, to determine optimum designs and components. High-level models, such as VISION, are used in design studies and analyses of cycle-related requirements. These flexible models are particularly useful in the preliminary design stage, when assumptions and requirements can change quickly.

Exploratory models, such as ADVISOR, allow analysts to investigate energy management strategies, interactions among components of various types and sizes, and the performance and energy implications of different powertrain designs. These are important in developing future plug-in and heavy-duty hybrid vehicles.

More detailed models, such as the Powertrain System Analysis Toolkit, provide in-depth analyses of components, events, and transients. And robust design integrates the latest computer-aided engineering and design tools with advanced design techniques to solve technical barriers and accelerate development.

The Laboratory's optimization tools and distributed computing capabilities complement this modeling work. Optimization tools help analysts find the best combinations of components and characteristics for a particular type of vehicle. For example, sometimes two or more design objectives—such as power and fuel economy—compete with each other; optimizing involves evaluating and comparing options to achieve the best overall effect. And analysts can tap into the considerable computational capability of NREL's distributed computing system, making the entire process more efficient.

NREL has also developed a tool to evaluate technical targets and R&D goals, estimate market penetration, and project the impacts of advanced vehicles on U.S. oil usage. For more information, and a list of vehicle simulation and analysis tools currently used at NREL, please see www.nrel.gov/vehiclesandfuels/vsa/simulation_tools.html.



Hybrid-electric vehicle (HEV) sales are still small, but high-efficiency vehicles are proving to be very popular. So, sales are expected to increase substantially. They also set the stage for "plug-in" HEVs, which could shift transportation energy use from largely imported oil to domestically generated electricity. There are already about 5 million flexible-fuel vehicles (FFVs) on the road that can use E85 fuel, a high-percentage blend of ethanol. The number of service stations selling E85 needs to grow proportionately to take advantage of the capabilities of this growing FFV fleet.