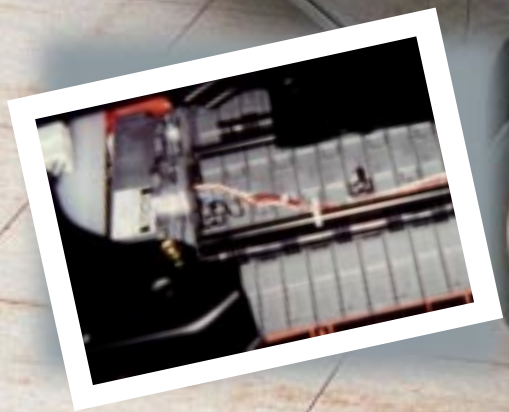
Clean ENERGY for the 21st Century

Office of Energy Efficiency and Renewable Energy

An introduction by the U.S. Department of Energy to commercially available advanced vehicle technologies

Technology Snapshot

featuring the Toyota Prius



What's Inside...

Welcome to the Clean Cities Advanced Vehicle Information Series

Dear Reader,

Twenty-first century transportation is not just a vision for the future — it's here today. Clean, fuel-efficient hybrid electric vehicles (HEVs) are now available, joining the alternative fuel vehicles already on the road. You may have seen HEVs in the news, at your local dealership, and even in your neighborhood. This brochure is the first of the U.S. Department of Energy's (DOE's) ***Technology Snapshots***, a suite of publications in the Clean Cities Advanced Vehicle Information Series that is designed to introduce the latest commercially available vehicle technologies to consumers across the country. Each Snapshot features a different vehicle and offers an objective, "plain English" explanation of how it works and how it differs from conventional vehicles. The web sites listed on the back cover of this brochure provide additional information about advanced transportation technology programs.

Although nothing can compare to sitting behind the wheel, each Snapshot gives you a feel for the featured vehicle by highlighting performance, vehicle safety, and the benefits the new technology delivers to you and your community. Are ***you*** ready to drive a cleaner, "greener" and more fuel-efficient vehicle?

Thomas J. Gross
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for Transportation Technologies
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What Is a Hybrid Electric Vehicle?

A hybrid is any vehicle that uses two or more sources of power — in today's HEVs, the two sources are electricity (from batteries) and mechanical power (from a small internal combustion engine). HEVs can offer the very low emissions of electric vehicles with the power and range of gasoline vehicles. They also offer up to 30 more miles per gallon, perform as well as or better than, and are just as safe as any comparable gasoline-powered car — and they never have to be plugged in for recharging. Widespread use of HEVs would help reduce our nation's growing dependence on foreign oil and cut greenhouse gas emissions by one-third to one-half.

How Do HEVs Work?

Hybrids can offer tremendous fuel economy and emissions benefits because they operate differently than conventional gasoline-fueled vehicles.

Gasoline Vehicle: The heat energy obtained by burning gasoline powers the engine, which drives the transmission that turns the wheels.

Electric Vehicle: A set of batteries provides electricity to a motor, which drives the wheels.

Hybrid Electric Vehicle: Not all hybrids are alike. There are many ways to combine the engine, motor/generator, and battery. Three basic hybrid configurations are the series, parallel, and split (or through-the-road) designs.

Series. The engine never directly powers the car. Instead, the engine drives the generator, and the generator can either charge the batteries or power an electric motor that drives the wheels.

Parallel. The engine connects to the transmission, as do the batteries and the electric motor. So both the engine and the generator/motor can supply power to the wheels, switching back and forth as driving conditions vary.

Split. The engine drives one axle and the electric motor drives the other. There is no connection between the engine and the electric components except "through the road."

Introducing the Toyota Prius

A New Type of Car...

Toyota's Prius combines features of both a "series" and "parallel" hybrid electric vehicle, and it is the world's first mass-produced HEV. The Prius is a breakthrough in many ways, combining an efficient gasoline-fueled internal combustion engine with a clean, quiet electric motor powered by a battery. Like other HEVs, the Prius has many innovative features:

- ***Regenerative braking:*** The motor recovers energy from the brakes when they slow down or stop the vehicle and uses it to recharge the battery.
- ***Lighter, smaller engine:*** To improve efficiency, the Prius engine is sized to accommodate its average power load, not its peak load. Most gasoline engines are sized for peak power requirements, yet most drivers need peak power only 1% of the time.
- ***Better fuel efficiency:*** The Prius consumes less fuel than vehicles powered by gasoline alone — partly because the engine is turned off when it's not needed. Conventional gasoline engines run constantly, regardless of power requirements.
- ***Lower emissions:*** The Prius reduces regulated tailpipe emissions by up to 90% and greenhouse gas emissions by about 50% compared with Tier 2 standards.
- ***More aerodynamic:*** The streamlined Prius exterior (0.29 coefficient of drag) reduces drag by about 14% compared with the typical family sedan.

...That Drives Like Any Other Car...

The Prius means more than just impressive fuel economy and lower emissions. It is a real car that does not have to be "plugged in" or fed expensive or hard-to-find fuels. It drives and accelerates like other gasoline-powered vehicles, and it feels like a comfortable five-passenger sedan.

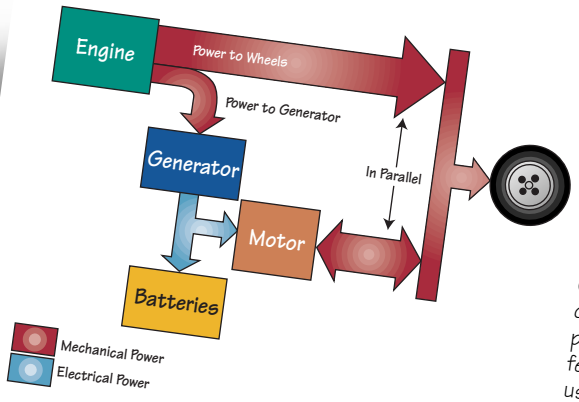
...Only Better.

Toyota's claims for the Prius are supported by independent laboratory testing by both DOE and the U.S. Environmental Protection Agency (EPA).

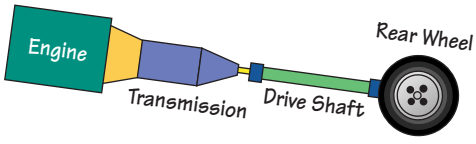
Hybrids may be the cars that convince the American public that advanced technology can be both affordable and convenient. The next few pages offer more details on the technology used in these vehicles and illustrate how HEVs can deliver a cleaner, comfortable drive *today.*

HEVs — Out of the Lab and onto the Road

What started out as a short-term solution to extend the range of electric cars may turn out to be one of the best options for increasing fuel economy and cutting greenhouse gas emissions on American roads. When automakers installed an onboard generator powered by an internal combustion engine in an electric car to make the car capable of longer trips, many viewed it as a temporary measure until better batteries were developed. But HEVs caught on in the auto industry and, after 20 years of study, a new generation of hybrids is taking center stage in the quest for cleaner, more efficient cars and trucks.



The Toyota Hybrid System (THS) (left) combines features of both the series and parallel systems (described opposite). The key to the THS is an electronically controlled power splitter that directs power from the engine to both the wheels and the generator. Compare the THS to a conventional gasoline engine powertrain (below); it has a few more components, but it uses them more efficiently.



Focus on Technology

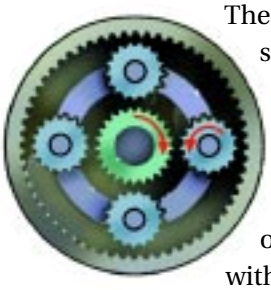
Prius Engine Helps Recharge the Battery

Why doesn't the Prius ever need to be plugged in for recharging? Because the car recharges its batteries primarily by using its own gasoline engine, in addition to regenerative braking. Some of the power from the engine is "split off" and stored in the car's battery pack. This "self-charging" system greatly enhances driving range — to more than 600 miles on a tank of gas in the city.

Prius Constantly "Talks" to Itself

The Prius has an electronic control system that "talks" to the car's key components and ensures that the car always operates in its most efficient mode — for lower fuel consumption and power output that instantly adjusts to driving conditions. The engine even shuts off when it isn't needed for acceleration or to recharge the battery.

THS Transmission Provides Seamless Shifting

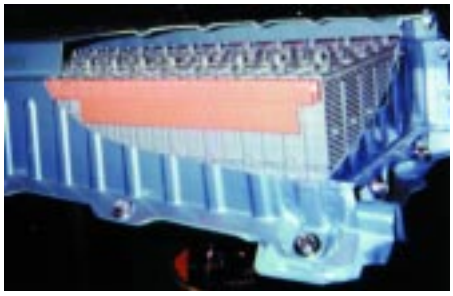


The THS transmission is not a conventional automatic transmission. There is only one gear set, with no clutch, starter, alternator, or torque converter. The system fluidly adjusts the operation of the gasoline engine, generator, and electric motor to match driving conditions. The key to this system is a planetary gear power-split device that allocates power from the gasoline engine to both the final drive and the generator. The generator produces the electrical power that is used to recharge the high-voltage battery pack and to power the electric motor. The generator also functions as a starter for the gasoline engine — no other starter is needed.

The result is a quiet and seamless system — in fact, the only way to know what mode the car is operating in is by checking the liquid crystal display (LCD) on the dashboard.

Innovative Battery Holds a Bigger Charge

The battery pack in the Prius is a nickel-metal hydride (NiMH) pack that operates at 274 volts. The Prius features a prismatic battery, in which the positive and negative plates are stacked rather than rolled (as in a typical cylindrical battery). The resulting surface area is larger, so the battery delivers more power and is more durable.



When engine demand is low, such as when starting, traveling at a light load, or stopping, the Prius is driven only by its electric motor, using battery power.

During normal travel, the gasoline engine engages as needed to (1) drive the wheels and/or (2) recharge the battery.

Key:

- Battery Pack
- Inverter
- Electric Motor
- Engine
- Generator

Inverter Extends Battery Life

An inverter changes the battery's DC power into AC power for use by the electric motor, and it also changes the generator's AC power into DC power to recharge the battery pack. It regulates the power from regenerative braking and extends battery life by always maintaining the proper charge.

Braking System Helps Improve Fuel Economy

When a driver slows down or steps on the brake in the Prius, the regenerative braking system converts kinetic energy from the motion of the wheels — normally dissipated as heat in the brakes — into electric current to help recharge the battery. About 20% of the total energy consumed by the Prius comes from regenerative braking, which contributes to the car's excellent fuel economy.

Technical Specifications

Powertrain: Toyota Hybrid System (THS), including:

- *Gasoline engine: 1.5-L, 16-valve, 4-cylinder, cast-aluminum block and head, EFI Atkinson-cycle VVTi (Variable Valve Timing with intelligence), 13:0:1 compression ratio, 70 hp at 4,500 rpm, 82 lb-ft of torque at 4,200 rpm*
- *Electric motor: Three-phase AC permanent magnet with peak power of 33 kW/44 hp at 1,040–5,600 rpm, peak torque of 350.0 N-m/258 lb/ft (0–400 rpm)*
- *Battery: Sealed nickel-metal hydride battery, 274 volts*

Transmission:	*Electronically controlled, continuously variable, power-split transaxle*
Max. speed:	*100 mph*
Acceleration:	*0–60 miles per hour in 12.7 seconds*
Fuel efficiency:	*52 mpg city/45 mpg highway**
Coefficient of drag:	*0.29 (drag for 5-passenger car is typically 0.355)*
Emissions:	*Meets California Super Ultra Low Emissions Vehicle (SULEV) standards*
Fuel tank:	*11.9 gallons*
Max. range:	*619 mi (city)/ 535 mi (highway)***
Passengers:	*5*
Length:	*169.6 in.*
Width:	*66.7 in.*
Height:	*57.6 in.*
Wheelbase:	*100.4 in.*
Weight:	*2,765 lb*
Cargo:	*10 ft^3*
Braking:	*Front disc/rear drum (hydraulic with power assist) with integrated regenerative system, ABS*
Steering:	*Rack and pinion, with power assist*
Turning circle:	*31.6 ft*
Suspension:	*Front: MacPherson strut Rear: torsion beam*

** EPA label values*

*** Based on 11.9-gal fuel tank and 52 mpg city/ 45 mpg highway.*

At full acceleration, the battery adds its power to the mix, which provides a very smooth and powerful response.

When decelerating or braking, the regenerative braking system acts as a generator to help recharge the battery.

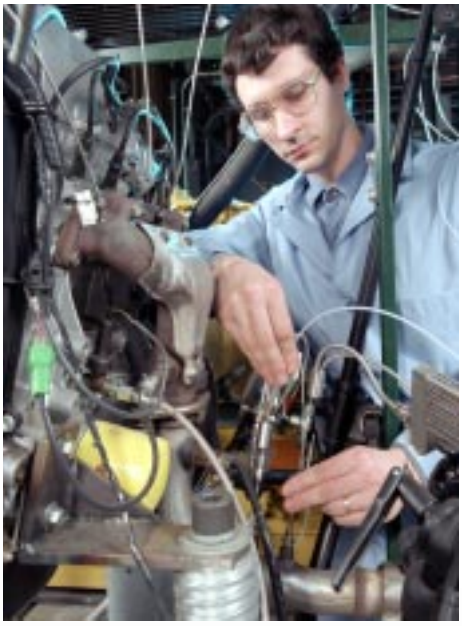
The engine shuts off when the car is idling or if engine demand is low. The gasoline engine runs only as needed to recharge the battery or run the air conditioner, which is why the Prius never has to be plugged in for recharging.

Independently Tested by the DOE and EPA

DOE Focuses on Prius Performance

Starting in March 1999, DOE conducted independent testing of the Prius at Argonne National Laboratory and the National Renewable Energy Laboratory (NREL). The testing goals included determining the operating performance of the hybrid technology and collecting data to determine the overall energy management performance of the entire vehicle and its individual components, including the batteries.

Argonne researchers focused primarily on the powertrain control and energy management systems, measuring numerous system functions: engine speed and mass airflow; exhaust gas and coolant temperature; generator and motor speeds; accumulated ampere-hours; battery voltage; battery, motor, and generator current; vehicle speed; carbon monoxide (CO), nitrogen oxides (NO_x), and hydrocarbon (HC) emissions; and fuel efficiency. NREL researchers focused on battery thermal management performance.



Work at DOE laboratories included developing an engine map — the set of data that relates an engine's fuel consumption, power output, and emissions; examining the vehicle's hybrid control strategy; collecting data on powertrain operation; outfitting a car for mobile testing during on-road city and highway driving; and extensive battery testing.

EPA Takes a Closeup Look at THS

In 1998, the U.S. Environmental Protection Agency evaluated the Prius THS technology over two test sequences involving the Federal Urban Dynamometer Driving Schedule and the Highway Fuel Economy Test (HFET).

The results of these tests are provided in the EPA report "Evaluation of a Toyota Prius Hybrid System," EPA420-R-98-006, August 1998, on the EPA website: www.epa.gov

Why Drive a Hybrid Electric Vehicle?

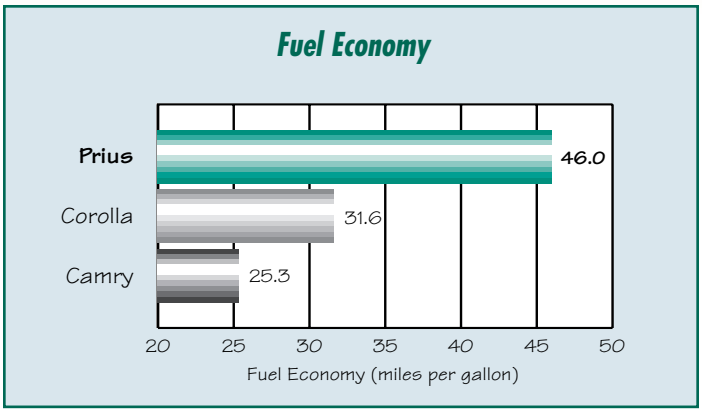
As the information in this brochure illustrates, the Prius and other HEVs are mechanically innovative, sophisticated vehicles. Many people might ask why they should drive these technological marvels when their current car does everything they want it to do. The two best reasons are (1) to improve mileage and (2) to reduce emissions.

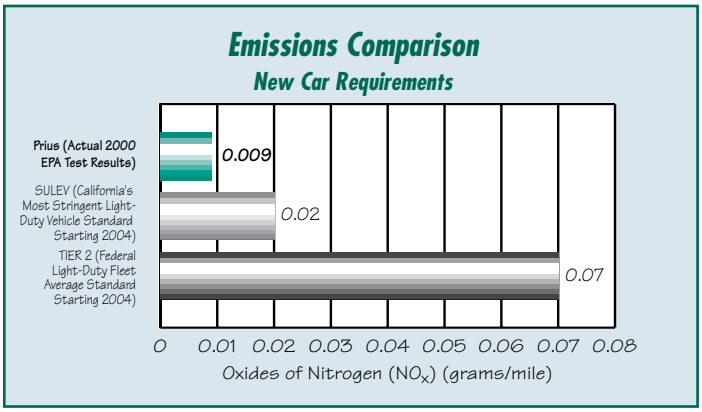
The Outlook on Oil

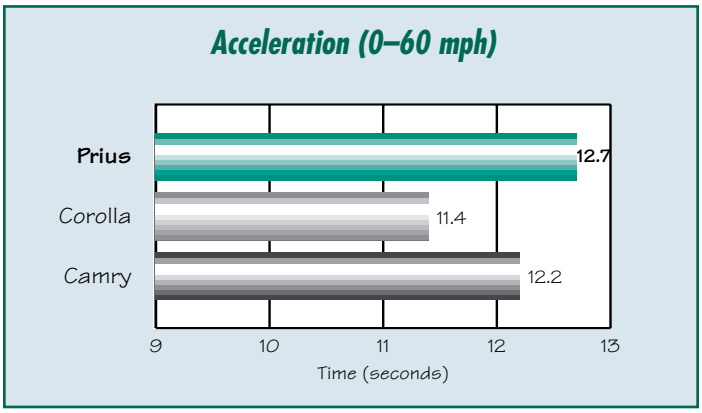
Most people dislike having to pay $20 or $30 or more for a tank of gas. Yet, the United States depends on petroleum for nearly 95% of its transportation energy — about 8 million barrels per day of petroleum products are used to fuel light trucks and cars. More than half of our petroleum is imported, and this percentage is growing, which is why oil imports represent one of the largest components of the U.S. trade deficit. And the demand for oil used for transportation will grow as the number of people and the number of miles they drive increase.

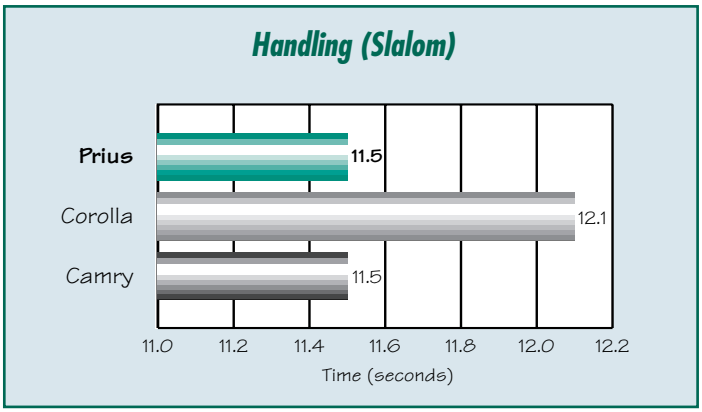
Air Emissions

Growing scientific evidence suggests that greenhouse gas emissions could contribute to a change in the earth's climate — and transportation, specifically the combustion of fossil fuels in our vehicles, accounts for a large portion of greenhouse gases. Moreover, EPA considers a number of other pollutants in vehicle emissions to be harmful to public health and the environment. Despite the substantial reductions in individual vehicle emissions over the last few decades, the millions of vehicles on our roads — which burn thousands of gallons of petroleum every second — account for a third of the country's air emissions.









Picture-Perfect Performance

DOE took its testing efforts on the road in September 2000. At the Route 66 Motor Speedway near Chicago, Argonne engineers tested the model year 2001 Prius against a similarly equipped 2001 Toyota Camry and 2001 Corolla to see how they compared in terms of fuel economy, acceleration, handling, and braking. The results are shown in the charts above and in the table at right.

The Prius truly appeals to people who want a car with excellent performance that is also friendly to the environment. The "Emissions Comparison" chart above illustrates how Prius almost eliminates harmful emissions — it already meets California Super Ultra Low Emission Vehicle (SULEV) standards that take effect in 2004 — without sacrificing performance (see table below). Prius reduces hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxides (NO_x) emissions by up to 90% and carbon dioxide (CO_2) and other GHG emissions by up to 50% relative to those of a comparable gasoline-fueled vehicle. But the vehicle can still handle as well as or better than comparable 5-passenger cars (see slalom and skid pad test results below), accelerate from 0 to 60 mph in under 13 seconds, and achieve fuel economy as high as 52 miles per gallon.

	Prius	Corolla LE	Camry LE
On-Road Fuel Economy (mpg)	**46.0**	31.6	25.3
EPA Fuel Economy (city/highway) (mpg)	**52/45**	29/33	23/32
Acceleration (sec) 0–60 mph	**12.69**	11.41	12.15
Slalom (sec)	**11.45**	12.10	11.46
Skid Pad (G)	**0.654**	0.667	0.651
Braking (ft from 60–0 mph)	**135.1**	173.6 *	198.2
Passenger/Luggage Volume (ft^3)	**89/12**	88/12	97/14

*Not equipped with anti-lock brakes.

The U.S. Department of Energy's mission is to enhance our nation's energy security, national security, and environmental quality, and to contribute to a better quality of life for all Americans. The widespread availability and use of alternative fuels and clean, energy-efficient, advanced technology vehicles (like those profiled in the Technology Snapshots) will help reduce U.S. dependence on foreign petroleum and promote clean air and healthier living in communities nationwide.

Prius Cleans Up with 5 Environmental Awards

- *United Nations Environmental Protection Award*
- *EPA's First Annual Global Climate Protection Award*
- *Sierra Club's "Excellence in Environmental Engineering Award"*
- *"Clean Car Salute" from the Clean Car Coalition, a group composed of state, regional, and national environmental organizations in the U.S.*
- *Exhibited at the Museum of Modern Art, "Different Roads: Automobiles for the Next Century"*

Related Web Sites

http://www.ott.doe.gov/

The U.S. Department of Energy's Office of Transportation Technologies (OTT) develops and promotes advanced transportation and alternative fuel vehicles and technologies.

http://www.ccities.doe.gov/

OTT's Clean Cities Program supports the deployment of alternative fuel vehicles and supporting infrastructure.

http://www.ott.doe.gov/hev/

OTT's Hybrid Electric Vehicle Program.

http://www.eren.doe.gov/EE/transportation_related.html

Related sites from government, educational, commercial, and organizational sources.

http://www.toyota.com

Toyota Motor Corporation web site.

http://www.fueleconomy.gov

The web-based version of the DOE/EPA Fuel Economy Guide.

Publishing services provided by Argonne National Laboratory