

Building a Better SUV

**A Blueprint for Saving Lives,
Money, and Gasoline**



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Union of Concerned Scientists
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The Union of Concerned Scientists is a nonprofit partnership of scientists and citizens combining rigorous scientific analysis, innovative policy development, and effective citizen advocacy to achieve practical environmental solutions.

The Union of Concerned Scientists Clean Vehicles Program develops and promotes strategies to reduce the adverse environmental impact of the U.S. transportation system.

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EXECUTIVE SUMMARY

SUVs are marketed to consumers as a safe and rugged alternative to the station wagon. The reality, however, is that automakers have offered consumers unsafe SUVs that place a heavy burden on both pocketbooks and the environment.

In 2002, 42,815 people lost their lives in U.S. highway fatalities—the highest level since 1990. SUVs and pickups accounted for more than 60 percent of the increase. At the same time, the fuel economy of light trucks (SUVs, pickups, and minivans) fell to its lowest level since 1981, forcing the average light truck owner to pay more than \$11,000 for gasoline over the life of the vehicle. This poor fuel economy contributes to a growing dependence on oil, rising imports, and a transportation sector that emits more global warming emissions than most countries release from all sectors combined.¹

Consumers want and deserve better. This report provides a blueprint for using existing technologies to build a better SUV—one that can save lives, money, and gasoline while providing consumers with the same size and performance they have today.

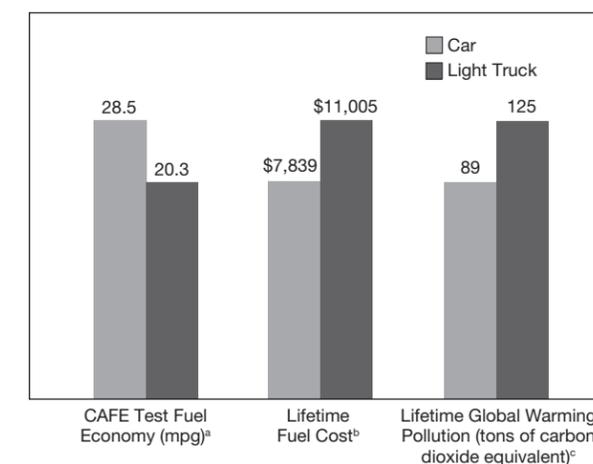
Fuel Economy and Pollution Loopholes

SUV sales increased by a factor of 20 between the early 1980s and 2002, and now represent one out of every four new car sales in the United States. Despite the dramatic rise in light truck sales and their primary use as passenger vehicles rather than work vehicles, SUVs, pickups, and

minivans are allowed to meet a much lower fuel economy standard than cars.

As a result, the average light truck's fuel economy was about 30 percent lower than the average car in 2002 (Figure ES-1). This translates into nearly \$3,200 more spent on gasoline over the truck's life, assuming a conservative gas price of \$1.40 per gallon. In addition, the average model year (MY) 2002 light truck produced 40 percent more emissions of the heat-trapping gases that cause global warming and roughly 1.5 to 5 times more nitrogen oxide emissions (a key smog-forming pollutant) than cars.

Figure ES-1 Lifetime Impact of the Average Model Year 2002 Car and Light Truck



NOTES:
 a. CAFE test fuel economy is from Hellman and Heavenrich, 2003.
 b. Lifetime fuel cost based on: average gasoline price of \$1.40 per gallon; 15-year average vehicle lifetime; annual mileage of 15,600 in the first year, declining by 4.5% per year; and real discount rate of 5% (equivalent to an 8% new car loan). On-road fuel economy assumed to be 18% below CAFE test value.
 c. Lifetime global warming gas emissions presented as carbon dioxide equivalent emissions from the vehicle tailpipe (19 pounds/gallon) and from gasoline manufacturing and delivery (5 pounds/gallon). Emissions from manufacturing, refrigerant leaks, and other sources are not included. Emissions are based on the same vehicle lifetime and mileage estimates used to calculate lifetime fuel cost.

¹ Only the United States, China, Russia, and Japan have higher total emissions from all sectors.

Safety Pitfalls

Consumers may perceive SUVs to be safer than cars, but the overall fatality rate for SUVs was actually eight percent worse than cars in 2000. Furthermore, in single-vehicle accidents resulting in rollovers, the fatality rate for SUVs rises to nearly three times that for cars (Figure ES-2). Rollover fatalities in SUVs and pickups accounted for the majority of the increase in all occupant fatalities in 2002.

SUVs and pickups also drive up the fatality rates in other vehicles because of their heavy, stiff frames, which act like battering rams in collisions with other vehicles. The added height of SUVs and pickups makes matters worse by allowing the truck to ride up over a car's bumper, negating many of that vehicle's safety features. Despite these problems, neither the government nor the automakers have established standards or taken significant steps to reduce rollovers and make SUVs less dangerous to others on the road.

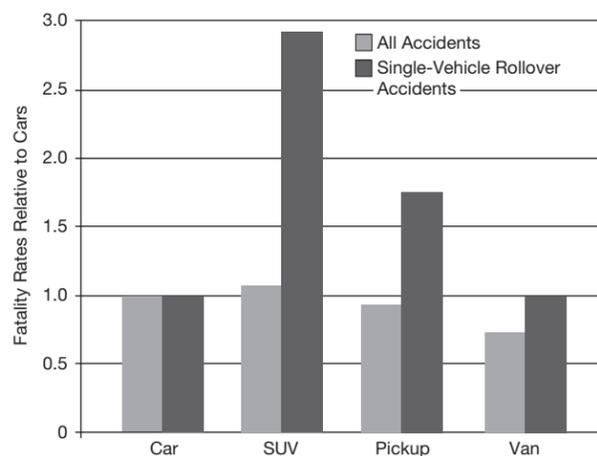
Building a Better SUV

Building a better SUV means offering consumers a vehicle they will want to buy—one that saves lives, money, and gasoline while providing the same performance they have come to expect. To demonstrate the safety and fuel economy potential of light trucks, the Union of Concerned Scientists developed a blueprint for a new SUV. This blueprint relies on improvements that could be made using existing safety and fuel economy technologies, all of which are on the road today in the United States, Europe, or Japan.

The UCS Guardian

The UCS Guardian and UCS Guardian XSE were designed to have the same size and acceleration as the most popular SUV in the United States today, the 21 miles per gallon (mpg) Ford Explorer. The Guardians were also designed to

Figure ES-2 **Relative Fatality Rates for Cars and Light Trucks (2000)**



SOURCE: Fatality data from NHTSA, 2001. Registration data from The Polk Company.

have the same or improved hauling capacity. Both vehicles accelerate from 0 to 60 mph in about nine seconds and have even better hill-climbing ability than the Explorer.

The Guardian achieves a fuel economy rating of 27.8 mpg by using a better engine, improved tires and aerodynamics, and a stronger but lighter unibody frame. Together, these technology improvements increase the price of the SUV by \$600 but pay for themselves in a little more than two years. Over the course of the vehicle's life, Guardian owners would save more than \$2,500 on gasoline.

The two most important safety improvements in the Guardian are an effective seat belt reminder system for all passengers and a sensor that activates the seat belt pretensioner to keep occupants firmly in their seats if the vehicle does roll over. Other safety improvements include making the vehicle lower and wider so it will be less likely to roll over in the first place, and implementing crush zones that make it less of a danger to others on the road. Together, these changes cost less than \$140 and would save more than 2,200 lives every year if all SUVs on the road used them.

The Guardian XSE achieves better than 36 mpg by adding an even more efficient engine, along with an efficient six-speed automatic transmission and more extensive use of high-strength steel and aluminum to reduce its weight. These improvements cost \$2,315, but still pay for themselves in 5.4 years and cut the vehicle's lifetime gasoline cost by more than \$4,300.

Added safety improvements include an electronic stability control system that uses a computer to help keep the vehicle from rolling over, and window curtain air bags that provide additional protection if the vehicle does roll over. These technologies cost only \$645 and would save more than 2,900 lives every year if all SUVs on the road used them.

Building Better Cars and Light Trucks

For the past 15 to 20 years, automakers have focused on building bigger and more powerful cars and trucks, and consumers now have vehicles with plenty of size and hauling power. But they also have vehicles that fail to provide the safety and fuel economy Americans want and deserve.

The technologies we used to design a better SUV can also be incorporated into cars, minivans, and pickups to give consumers better choices. Light trucks with these improvements could match the current fuel economy standard for cars (27.5 mpg) by MY 2008, cutting our oil use by 800,000 barrels per day in 2015. Putting all of these technologies to work in both cars and trucks would result in safer highways and new vehicles that could reach 40 mpg by 2014. This would increase U.S. oil savings to two million barrels per day in 2015.

Automakers have the necessary technologies in hand to spend the next decade and beyond focused on saving thousands of lives and billions of dollars at the pump every year. The UCS Guardian and

UCS Guardian XSE provide a blueprint for a better SUV that can deliver these benefits without forcing consumers to sacrifice the size and performance they have today.

Ford Explorer XLT

Engine 4-liter V6, 210 hp	Costs and Savings MSRP: \$29,200	
Transmission 5-speed automatic	Lifetime Fuel Cost: \$10,538	
Body standard aerodynamics standard tires body-on-frame construction 4,500 pounds	Total Cost: \$39,738	
Performance 0-60 mph in 8.9 seconds 18% hill grade at 50 mph	<i>fuel economy payback:</i> n/a	
Safety rollover rating: 2 out of 5 stars (2WD) basic minimal safety features	<i>lifetime net savings:</i> n/a	
	Annual Fatality Reduction (All SUVs) occupant life savings: n/a non-occupant life savings: n/a	
	Lifetime Emissions global warming gases: 119 tons	
	Fuel Economy (MPG)	
	21.2 CAFE Test	18.0 EPA Adjusted

UCS Guardian

Engine 3.1-liter VTEC V6, 225 hp	Costs and Savings MSRP: \$29,935	
Transmission 5-speed automatic	Lifetime Fuel Cost: \$8,036	
Body improved aerodynamics low-resistance tires unibody construction 4,100 pounds	Total Cost: \$37,971	
Performance 0-60 mph in 8.9 seconds 25% hill grade at 50 mph	<i>fuel economy payback:</i> 2.1 years	
Safety rollover rating: 5 out of 5 stars stronger roof, better seat belts, improved crash absorption	<i>lifetime net savings:</i> \$1,767	
	Annual Fatality Reduction (All SUVs) occupant life savings: 1,925 non-occupant life savings: 350	
	Lifetime Emissions global warming gases: 91 tons	
	Fuel Economy (MPG)	
	27.8 CAFE Test	23.6 EPA Adjusted

UCS Guardian XSE

Engine 2.3-liter stoich-GDI V6, 170 hp	Costs and Savings MSRP: \$32,160	
Transmission 6-speed automatic, no torque converter	Lifetime Fuel Cost: \$6,154	
Body improved aerodynamics low-resistance tires unibody construction 3,150 pounds	Total Cost: \$38,314	
Performance 0-60 mph in 8.9 seconds 22% hill grade at 50 mph	<i>fuel economy payback:</i> 5.4 years	
Safety rollover rating: 5+ out of 5 stars stronger roof, better seat belts, window curtain air bags, electronic stability control, improved crash absorption	<i>lifetime net savings:</i> \$1,424	
	Annual Fatality Reduction (All SUVs) occupant life savings: 2,550 non-occupant life savings: >350	
	Lifetime Emissions global warming gases: 70 tons	
	Fuel Economy (MPG)	
	36.3 CAFE Test	30.7 EPA Adjusted

BUILDING A BETTER SUV

Model year 2002 was a very good year for automakers selling SUVs, pickups, and minivans—the vehicle class known as “light-duty trucks.” Sales of these high-profit vehicles reached more than 7.5 million, a new record that represents a four-fold increase during the past 20 years (Hellman and Heavenrich, 2003) (Figure 1).

However, 2002 was not a very good year for SUV and pickup truck owners and those who share the roads with them. Highway fatality rates climbed to the highest level since 1990, with SUVs and pickups accounting for the majority of the increase (NHTSA, 2003b). Adding insult to fatality, light truck fuel economy fell to its lowest level since 1981, forcing the average light truck owner to pay more than \$11,000 for gasoline over the life of the vehicle.

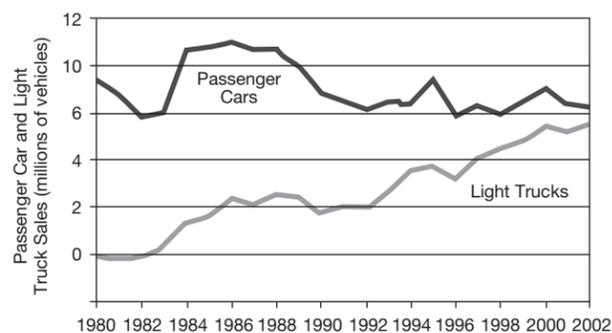
It was also not a very good year for oil dependence or the environment. U.S. dependence on oil continued to grow unabated as the country consumed nearly 20 million barrels of oil every day, more than half of which was imported. As a result, consumers sent about \$200,000 every minute overseas to buy oil.² And with average new vehicle fuel economy dropping to its lowest point in more than 20 years, the average model year (MY) 2002 passenger vehicle, over the course of its lifetime, now pumps out about 83 tons of the heat-trapping gases that cause global warming. Another 22 tons will be released by the production and delivery of the gasoline that vehicle uses.

The poster child for these trends of increased fatalities, oil dependence, fuel costs, and environmental degradation is the SUV. SUV sales increased by a factor of 20 between the early 1980s and 2002, and now represent one out of every four new car sales in the United States (Figure 2). The popularity of SUVs is not surprising, considering that they are marketed to consumers as a safe and rugged alternative to the station wagon. The reality, however, is that automakers offer consumers unsafe SUVs that also place a heavy burden on consumers' pocketbooks and the environment.

Automakers have let U.S. consumers down by not putting existing technology to work to make safer SUVs, pickup trucks, and minivans that go farther on a gallon of gas. And the U.S. government has failed to put regulations in place that would require automakers to do so.

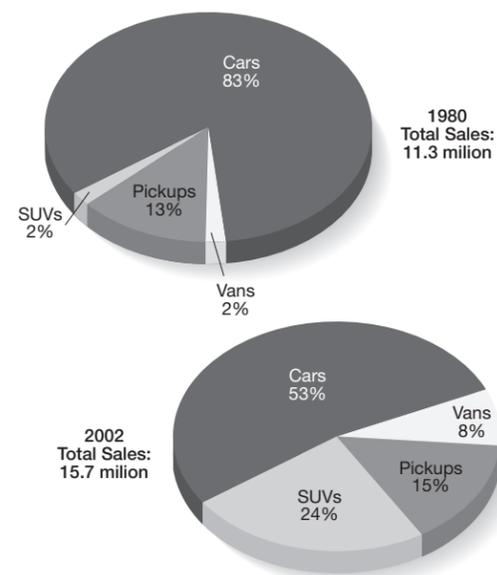
This report provides a blueprint for using existing technologies that can ensure SUVs and

Figure 1 **Historic Vehicle Sales**



SOURCE: Hellman and Heavenrich, 2003.

Figure 2 **The Changing Vehicle Sales Mix: 1980 vs. 2002**



SOURCE: Hellman and Heavenrich, 2003.

other light trucks become a part of the solution instead of the problem. These technologies are put to work in the design and simulation of two SUVs, the UCS Guardian and the UCS Guardian XSE. Our analysis shows that these SUVs could achieve significant improvements in fuel economy and safety while maintaining size and performance. The fuel economy improvements can pay for themselves in a few years by reducing the cost to fill up at the pump, and the safety improvements can result in thousands of lives saved each year if all SUVs on the road put these technologies to work.

If this blueprint is followed, consumers will have the freedom to choose the car or light truck that meets their needs while guarding their lives, saving the lives of others on the road, protecting their wallets from high gas prices, and reducing the impact they have on U.S. oil dependence and the environment.

Gambling with Our Wallets, Energy Security, and Environment

Today's consumers want to save money at the gas pump, and they want choices that will enable them to reduce our nation's dependence on oil and cut air pollution. As described below, these issues have not been adequately addressed by automakers or government, creating a hole that needs to be filled with a better SUV.

FUEL ECONOMY

The fuel economy of the average new SUV in 2002 was only about 20.3 miles per gallon (mpg) according to federal tests (Hellman and Heavenrich, 2003). The fuel economy of the average new pickup was only 19.3 mpg. In other words, the average new pickup or SUV in 2002 used about 1.4 times as much fuel as the average car.

This increased gasoline use translates directly into increased expenditures for gasoline. The owner of the average light truck purchased in 2002 will pay about \$11,000 for gasoline over the life of the vehicle. The average car owner will pay only about \$7,800 (Figure 3, p.6). Thus, light truck owners spend an average of \$3,200 more on gas over the lifetime of their vehicles than car owners, all because of poor fuel economy. And, because we import about 55 percent of the oil used to make our gasoline, a significant portion of that extra \$3,200 is being sent overseas.

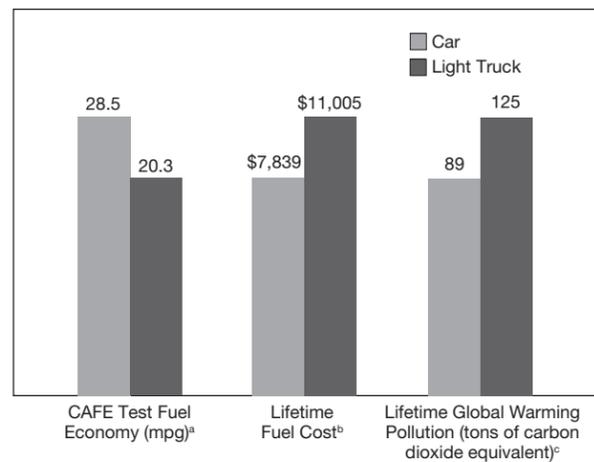
Two key reasons for the low fuel economy of SUVs are weight and shape. Because SUVs and pickups are more than 1,000 pounds heavier than the average car,³ it takes 30 percent more power for them to accelerate. In addition, the tall, blocky shape of most SUVs makes for a very non-aerodynamic vehicle.

Light trucks also trail cars on fuel economy because they are behind on technology. For

² Oil, as used here, includes crude oil and other petroleum products. The figure of \$200,000 per minute is based on 11.5 million barrels per day (EIA, 2003) at \$25 per barrel.

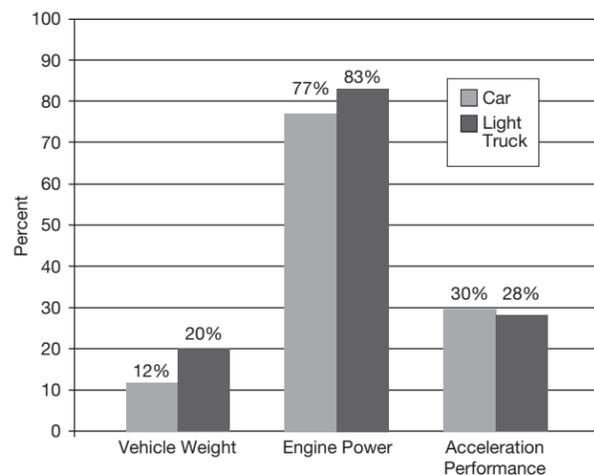
³ In 2002, the average new SUV weighed 4,525 pounds; the average new pickup weighed 4,694 pounds; and the average new car weighed 3,406 pounds (Hellman and Heavenrich, 2003).

Figure 3 Lifetime Impact of the Average Model Year 2002 Car and Light Truck



NOTES:
 a. CAFE test fuel economy is from Hellman and Heavenrich, 2003.
 b. Lifetime fuel cost based on: average gasoline price of \$1.40 per gallon; 15-year average vehicle lifetime; annual mileage of 15,600 in the first year, declining by 4.5% per year; and real discount rate of 5% (equivalent to an 8% new car loan). On-road fuel economy assumed to be 18% below CAFE test value.
 c. Lifetime global warming gas emissions presented as carbon dioxide equivalent emissions from the vehicle tailpipe (19 pounds/gallon) and from gasoline manufacturing and delivery (5 pounds/gallon). Emissions from manufacturing, refrigerant leaks, and other sources are not included. Emissions are based on the same vehicle lifetime and mileage estimates used to calculate lifetime fuel cost.

Figure 4 Increase in Average Passenger Vehicle Attributes (1982-2002)



SOURCE: Hellman and Heavenrich, 2003.

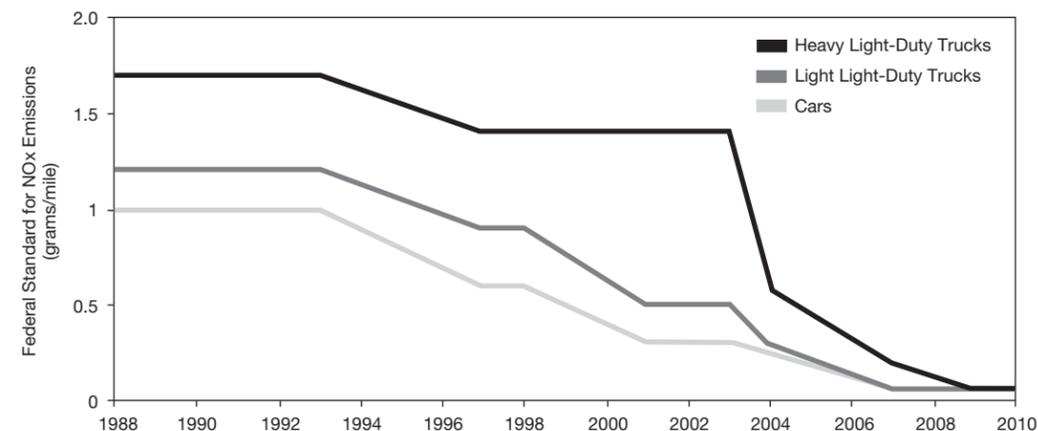
example, engines with four valves per cylinder run more efficiently than those with only two. And yet only about 32 percent of new light trucks had this technology in 2002 compared with more than 64 percent of cars (Hellman and Heavenrich, 2003).

Finally, the low fuel economy of today's light trucks is also a function of the same 20-year trend being followed by all cars and light trucks toward increased weight, power, and performance. Since 1982, the weight of the average light truck has increased by 20 percent and engine horsepower has increased by more than 80 percent (Figure 4).

Government inaction on fuel economy. More than 25 years ago, the government did act on fuel economy due to the gasoline crisis of the early 1970s. The Energy Policy and Conservation Act of 1975 established fuel economy standards for automakers, the so-called Corporate Average Fuel Economy (CAFE) standards. CAFE nearly doubled the fuel economy of passenger cars over a period of 10 years, and improved light truck fuel economy by about 60 percent. However, from 1985 through 2002, there were no improvements to fuel economy standards other than increases and decreases of a few tenths of a mile per gallon.

Because light trucks represented less than 20 percent of the market when CAFE standards were first established, and were primarily used for farming, construction, or other work purposes, they were treated differently from cars. Congress set a target of 27.5 mpg for cars to reach by 1985, and that standard remains in place today. The legislature gave the National Highway Traffic Safety Administration (NHTSA) the authority to set fuel economy standards for light trucks, and the agency established a target of 20.5 mpg by 1987. Nine years later, despite a doubling in light truck market share and the transition of SUVs, pickups, and minivans from work vehicles to passenger vehicles, the CAFE standard for

Figure 5 The Gap in Air Pollution Standards



SOURCE: Mark, 1999 and EPA, 2003.
 NOTE: Light light-duty trucks have a gross vehicle weight rating (GVWR) of less than 6,000 pounds. Heavy light-duty trucks have a GVWR of 6,000 to 8,500 pounds.

light trucks peaked at only 20.7 mpg, where it remains today.

In 2003, with light trucks representing about half of the new vehicle market, NHTSA finalized a seven percent increase in the light truck CAFE standard beginning in MY 2005 and reaching its target by MY 2007 (NHTSA, 2003c). Although this 1.5-mpg increase in light truck fuel economy will be the largest increase in the standard in more than 20 years, it will save only about one day's worth of oil each year between 2005 and 2010.⁴ This falls far short of the fuel economy potential outlined in this report.

AIR POLLUTION

Our cars and trucks emit a variety of air pollutants as a result of burning gasoline. Two of the pollutants, hydrocarbons (HC) and nitrogen oxides (NOx), mix with sunlight to form ozone, one of the key ingredients of the smog that threatens public health. Carbon monoxide (CO)

is another health hazard (primarily in winter), and particulate matter (PM) can lodge deep in the lungs and lead to respiratory problems and possibly cancer. These four are referred to as criteria pollutants.

Significant progress has been made in reducing the emission of criteria pollutants from cars and trucks over the past three decades. But just as light trucks have been treated differently from cars in terms of fuel economy, they also receive special treatment when it comes to air pollution. For example, "light" light-duty trucks (those with a gross vehicle weight below 6,000 pounds) are currently allowed to emit more than 1.5 times more nitrogen oxides than cars (Figure 5). "Heavy" light-duty trucks (those with a gross vehicle weight between 6,000 and 8,500 pounds) are allowed to emit more than four times the nitrogen oxides of cars.

Given advances in catalyst and engine control technology, this gap is unnecessary, but truck engines have nevertheless fallen behind cars

⁴ The savings over the six-year period (2005-2010) are estimated at 5.9 billion gallons (140 million barrels) of oil, or about 23 million barrels per day. In 2002, the United States used approximately 20 million barrels of oil each day. These savings disappear if NHTSA or Congress extends the 0.9- to 1.2-mpg credit automakers can receive for selling vehicles capable of running on either gasoline or an alternative fuel such as ethanol, but effectively always run on gasoline (because most owners don't know they have a choice and there are few places to buy alternative fuels).

technologically. The gap is also influenced by the increased power needs of trucks due to their extra bulk.

Another important set of air pollutants are the heat-trapping gases, such as carbon dioxide and air conditioning refrigerants, linked to global warming. These gases, which are a result of the low fuel economy of light trucks, the use of a high-carbon fuel such as gasoline, and poor control of refrigerant leaks, remain in the atmosphere for more than 100 years, contributing to an increase in Earth's average surface temperature that could reach 2.5 to 10.4°F (1.4 to 5.8°C) between 2000 and 2100 (IPCC, 2001).

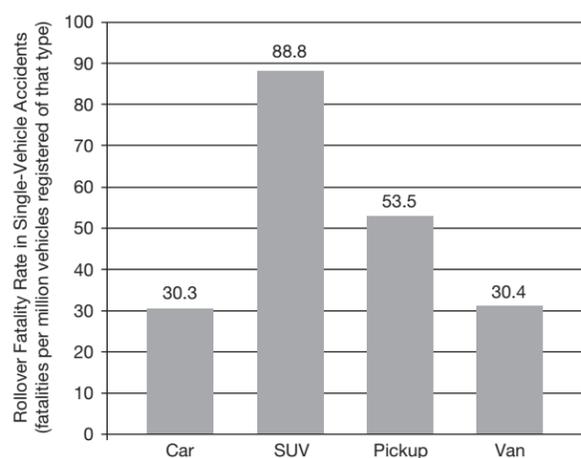
During its lifetime, the average light truck sold in 2002 will emit about 99 tons of these heat-trapping gases from its tailpipe. Another 26 tons will be released by the production and delivery of the gasoline this vehicle uses, for a total of 125 tons of global warming emissions during the truck's lifetime (Figure 3, p.6).

Government action and inaction on emissions. Compared with fuel economy, the U.S. government has been relatively consistent in cleaning up criteria pollutants. There is room for more progress, however.

Most recently, the so-called Tier 2 standards were established for criteria pollutants and phase in from 2004 to 2009. Though these new standards will finally eliminate the separate standards for trucks and cars by 2009, they still do not account for the smallest of particulate matter, the ultra-fine particles that can lodge deep within the lungs and cause significant respiratory problems. Tier 2 standards also do not adequately address the toxicity of vehicle exhaust.

U.S. government action on heat-trapping emissions has been effectively nonexistent. No federal regulations exist to curb greenhouse gases, and the current administration has refused to endorse the Kyoto Protocol to cut such emissions.

Figure 6 **U.S. Fatality Rate for Passenger Cars and Trucks in Single-Vehicle Rollovers (2000)**



SOURCE: Based on individual fatality statistics from NHTSA's Federal Accident Reporting System (FARS) and vehicle registration data from The Polk Company.

Existing laws designed to stimulate the use of alternative fuels could help shift vehicles to lower-carbon fuels, but they are not being enforced or effectively implemented.

Gambling with Our Lives

Two of the most important safety issues for light trucks are the high fatality rate of drivers in SUVs and pickups involved in rollover accidents, and the danger of these vehicles to others on the road. As described below, automakers have not provided consumers with safe SUV design choices, and the U.S. government has failed to require automakers to do so.

ROLLOVERS

The most dangerous type of accident for an SUV or pickup driver is one where the vehicle rolls over. SUV occupants were nearly three times as likely to die from a rollover compared with car occupants in 2000 (Figure 6). Pickup drivers were nearly two times as likely to die in a rollover. Rollover fatality rates in vans (primarily minivans) were about the same as cars. All told, more than

51,500 people died in light trucks due to rollovers from 1991 through 2001 (Deutermann, 2002; NHTSA, 2002).

SUVs and pickups are more likely to roll over than other vehicles on the road for a number of reasons. The most critical is the tendency of the vehicle's rear end to slide out in a turn or emergency maneuver, often referred to as oversteer, then slide back and forth, or yaw ("fishtail"), as the driver tries to compensate. This motion causes the vehicle to slide sideways and ultimately flip over one or more times. The height and width of SUVs and pickups increase the likelihood of a rollover once the vehicle is moving sideways, and its weight distribution, tires, tire pressure, and suspension characteristics can also contribute to rollovers.

When SUVs and pickups do roll over, they fail to provide their occupants with adequate protection from the two main causes of severe rollover injuries: occupant ejection and "roof crush." Increased roof strength, seat belt use, seat belt activation, and the use of other countermeasures can minimize the severity of injuries, but it should be noted that occupant ejection can occur whether the occupant is belted or not, because even partial ejection of the head or torso can lead to severe injuries.⁵

Government inaction on rollovers. Rollover casualties have been a focus of government research, regulation, and litigation for more than 30 years. In 1970, the National Highway Safety Bureau (NHSB) proposed a test for ensuring that vehicle occupants would not be ejected in a rollover.⁶ Unfortunately, this test was made optional, and

has almost never been used to certify a new production vehicle.

In the mid-1970s, the government acknowledged the problem of oversteer in its Experimental Safety Vehicle specifications, which required that these vehicles understeer in handling tests (Alexander, 1974). Yet no standard was ever established.

In 1971, the NHSB proposed to protect occupants from roof crush by implementing a rigorous static test of roof strength (NHSB, 1971). The American auto industry, however, urged it to substitute a weaker standard developed by General Motors (SAE, 1968), and in 1972, NHTSA adopted a relatively weak "temporary" roof crush standard that has remained in place ever since.

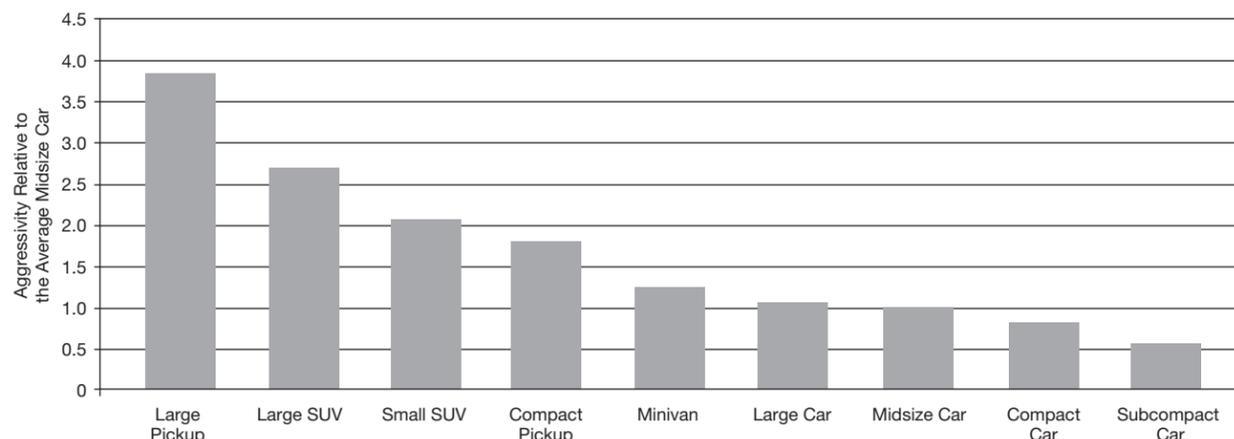
Despite the implementation of this new standard, roof crush deaths in rollovers continued to increase throughout the following decade. A 1989 NHTSA evaluation of the standard found there had been no significant reduction in rollover casualties during the previous 12 years (Kahane, 1989). Nevertheless, NHTSA extended the inadequate standard in 1994 to light trucks below 6,000 pounds gross vehicle weight rating (GVWR). To date, there is no roof crush standard for light trucks above 6,000 pounds GVWR.

NHTSA did at least act to warn consumers of the rollover propensity of light trucks after being petitioned by the Consumers Union in 1988.⁷ In the early 1990s, it promulgated a requirement that the most rollover-prone light trucks at the time include a rollover warning label in their owner's manuals and on their sun visors. And in 2000,

⁵ Partial ejection occurs in a rollover when roof crush breaks the vehicle's windows (or the windows are already open). This allows an occupant's head or torso to fall outside the vehicle while he or she remains belted inside.

⁶ 49 C.F.R. 571.208 §5.3. In the test specified in this standard, the vehicle is carried laterally on a dolly at a speed of 30 mph and a roll angle of 23°. The dolly is stopped suddenly, and the vehicle flies off and begins to roll. Typically, the vehicle rolls several times before coming to rest. To pass the test, no part of the dummies inside the vehicle may go outside the vehicle during the test.

⁷ Letter from Kristen M. Rand, Consumers Union, to National Highway Traffic Safety Administrator, dated June 2, 1988. NHTSA granted this petition on September 1, 1988.

Figure 7 **Relative Aggressivity in Vehicle-to-Vehicle Crashes (1995–1999)**

SOURCE: Summers, 2001.

NOTE: NHTSA aggressivity metric (deaths in the other vehicle divided by 1,000 police-reported crashes with the subject vehicle) has been normalized relative to midsize cars.

it added a mathematical calculation, rather than an actual test, to evaluate rollover propensity for its vehicle safety rating system (the New Car Assessment Program).⁸ NHTSA also amended an existing standard to require interior padding in the head impact area of the roof.⁹

However, despite these measures, rollover-related deaths increased to more than 10,600 by 2001—about one-third of all passenger vehicle fatalities that year (NHTSA, 2002). More than half of these rollover fatalities involved roof crush or potential occupant ejection.

VEHICLE AGGRESSIVITY

There are many different ways to define aggressivity, but in general, it is the propensity of a vehicle to inflict damage on others in a collision with another vehicle.

NHTSA defines the aggressivity of vehicle “A” as the number of fatalities in other vehicles per each accident with vehicle “A”. By this measure, if you were in an accident with an SUV such as the Ford Explorer, Dodge Durango, or Chevy Blazer

between 1995 and 1999, you were about 2.5 times more likely to die than if you were in an accident with the average midsize car (Figure 7). If you were in an accident with a large pickup such as the Ford F Series, Chevy Silverado, or Dodge Ram, you were nearly four times more likely to die than if you were in an accident with the average midsize car.

The aggressivity of SUVs and pickups is a direct result of the fact that they are, in general, heavier, stiffer, and taller than cars. The weight of a vehicle determines how much destructive force it brings to an accident, and because SUVs and pickups are more than 1,000 pounds heavier than the average car, their aggressivity is partly due to the increased force they bring to an accident.

In addition, most SUVs and pickups are made using stiff frame rails that act like rams in accidents with other vehicles, while cars, minivans, and many small SUVs are designed with energy-absorbing structures. This means SUVs and pickups are also more aggressive because they force other vehicles to absorb more of the destructive force

they bring to an accident. Cars and minivans, on the other hand, each do their fair share of absorbing the force transferred in accidents with each other.

Finally, SUVs and pickups are typically taller than the average vehicle on the road. In frontal and rear-end accidents, the SUV or pickup’s bumper is more likely to ride up over a car’s bumper, negating the safety features of the car. In side accidents, the SUV or pickup’s bumper can ride up over a car’s doorframe and drive right into the passenger compartment. This form of aggressivity is sometimes referred to as vehicle incompatibility.

Government inaction on aggressivity. NHTSA began work on the general issues of aggressivity and compatibility decades ago, when it investigated the compatibility of cars involved in accidents with other cars. However, it was not until the mid-1990s that NHTSA began to investigate the aggressivity of light trucks (Hollowell, 1996). While the agency has continued to study the issue, it has not issued standards directly intended to reduce aggressivity in light trucks.

Building a Better SUV

Building a better SUV means offering consumers a vehicle they will want to buy—one that saves lives, money, and gasoline while providing the same performance as today. This can be achieved by improving SUV design with technologies already in the hands of automakers. Most of these technologies are used in only a small fraction of the trucks sold each year; others are not yet used in trucks but can be found in cars in the United States, Europe, and Japan.

To demonstrate the safety and fuel economy potential of light trucks, the Union of Concerned Scientists developed a blueprint for a new SUV

using existing technologies. Out of several possible configurations, two technology packages were chosen: the UCS Guardian and UCS Guardian XSE. Both models provide significant improvements in safety and fuel economy; the Guardian XSE offers added safety and environmental features for a somewhat higher price.

These vehicles were designed to have the same acceleration as a 2001 Ford Explorer XLT and the same or improved hauling capacity. The fuel economy performance of all three vehicles was evaluated using a computer simulation tool, and safety performance was evaluated based on changes to existing vehicle risk factors (see Appendix B for more details about our methodology).

THE FORD EXPLORER XLT

The Ford Explorer is the most popular SUV in the United States, and at more than 400,000 sales per year, even outsells the best-selling cars, the Toyota Camry and Honda Accord (Ward’s, 2003). The 2002 two-wheel drive version of the Explorer XLT had a base price of about \$29,200 (*Automotive News*, 2002).

Fuel economy technology. The base model 2001 Explorer XLT included a 4.0-liter, single overhead cam V6 engine with two valves per cylinder and a five-speed automatic transmission (Ford, 2003).¹⁰ The Explorer engine produces about 210 horsepower, or about 157 kW, for a specific power rating of 39 kW/liter. This rating was about average for light trucks in 2001, but approximately 15 percent lower than the average car.

The 4,500-pound Explorer was able to accelerate from 0 to 60 miles per hour in about 9 to 10 seconds. The two-wheel drive version achieved a CAFE test fuel economy rating of 21.5 mpg, while the four-wheel drive version achieved 19.3 mpg.

⁸ 49 C.F.R. 575.105. Docket No. NHTSA 2000-8298.

⁹ 66 F.R. 53376, Federal Motor Vehicle Safety Standards, Roof Crush Resistance [Docket No. NHTSA-1999-5572; Notice 2], October 22, 2001.

¹⁰ The 2002 Explorer XLT, while different in styling from 2001, uses an updated version of the same basic drivetrain, though the engine power increased a slight amount.

Because the CAFE test does not actually represent real-world conditions, the Environmental Protection Agency's (EPA) adjusted fuel economy rating¹¹ for the two-wheel drive Explorer was 18 mpg, and 16 mpg for the four-wheel drive version.

Safety technology. The 2001 Ford Explorer received only two out of a possible five stars in NHTSA's rollover ratings (NHTSA, 2003). It was equipped with only the most basic standard safety features, such as driver and passenger air bags, anti-lock brakes, safety belt pretensioners, and a basic belt-use reminder system for the driver. None of these directly address the problems of rollover or aggressivity.

For 2002, Ford redesigned the Explorer with a longer wheelbase, increased width, and rear-wheel independent suspension, all of which reduce the tendency of the vehicle to roll over. However, the two-wheel drive Explorer still received only two out of five stars from NHTSA. The four-wheel drive Explorer improved its rollover rating to three stars (NHTSA, 2003). Ford also began offering window curtain air bags and electronic stability control systems, but these optional features must be specifically requested, at a relatively high premium.

The Ford Explorer is still built using the heavy and stiff body-on-frame construction that reduces the vehicle's ability to absorb its share of the forces in an accident, making it a danger to other vehicles on the road. It is also still relatively tall compared with the average car on the road today, leaving significant potential for the Explorer to ride up over the bumpers and doorframes of other vehicles.

The performance of this vehicle, as modeled, and the two improved vehicles described below, are compared in Table 1.

THE UCS GUARDIAN

The UCS Guardian is a highly cost-effective new SUV design. All of the technologies and design techniques employed in the Guardian are available in mass-produced vehicles in the United States today, and could already have been incorporated into vehicles such as the Ford Explorer, Chevy TrailBlazer, and Dodge Durango. Since these technologies remain on the shelf, however, they cannot be easily integrated into these vehicles until their next major redesign, which generally occurs every four to six years. Thus, the Explorer, which was redesigned for MY 2002, could incorporate these technologies by MY 2007 or 2008.

Fuel economy improvements in the Guardian would cost consumers about \$600, but would pay for themselves within a little more than two years at a conservative gasoline price of \$1.40 per gallon. Compared with the Ford Explorer, the Guardian would save its owner more than \$2,500 on gasoline over the vehicle's typical 15-year life. Safety improvements in the Guardian would cost consumers less than \$140 and would save as many as 2,275 lives per year if all SUVs on the road incorporated them.

A summary of the Guardian's safety and fuel economy performance, along with the associated savings, is shown in Table 1.

Fuel economy improvements. Instead of using an engine similar to the Ford Explorer, our design incorporates a 225-horsepower, 3.1-liter, dual overhead cam V6 engine with four valves per cylinder and variable valve control technology, along with low-friction design and engine oil. This slightly downsized new engine provides about a 13 percent increase in fuel economy compared

Table 1 **Building a Better SUV: Ford Explorer Case Study^a**

	Ford Explorer XLT	UCS Guardian	UCS Guardian XSE
Technology Status ^b	Baseline	U.S. Mass Production	Worldwide Mass Production
Fuel Economy			
CAFE Test (mpg) ^c	21.2	27.8	36.3
EPA Adjusted (mpg) ^d	18.0	23.6	30.7
Performance			
0-60 acceleration (seconds) ^e	8.9	8.9	8.9
Hill grade at 50 mph ^f	18%	25%	22%
Annual Lives Saved			
Occupant Lives Saved ^g	N/A	1,925	2,550
Other Lives Saved ^h	N/A	350	>350
Lifetime Impact			
Fuel Cost ⁱ	\$10,538	\$8,036	\$6,154
Global Warming Gases (tons) ^j	119	91	70
Technology Price^k			
Fuel Economy Technology	N/A	\$600	\$2,315
Safety Technology	N/A	\$135	\$645
Fuel Economy Savings			
Lifetime Fuel Cost Savings ^l	N/A	\$2,502	\$4,383
Payback (years) ^{m,n}	N/A	2.1	5.4

NOTES:

- See appendices for discussion of methodology, data, and detailed results.
- The UCS Guardian uses technology currently or soon to be mass produced in the United States and can be found in cars and trucks today. The UCS Guardian XSE uses technology currently mass produced in the United States or another country and can be found in cars today.
- Composite city/highway fuel economy over the EPA test cycle used in determining Corporate Average Fuel Economy (CAFE) compliance.
- CAFE test results adjusted by EPA factors to better represent on-road performance.
- Acceleration time from stop to 60 miles per hour.
- The hill grade that the vehicle can climb at 50 miles per hour. A higher percentage means a steeper hill. The vehicle may have to downshift to achieve this performance.
- Projected number of SUV occupants whose lives would be saved if all SUVs on the road were replaced with SUVs using this design. Assumes SUV registrations will grow from 20 million in 2000 to 35 million over the next 5-10 years.
- Projected number of other people on the road whose lives would be saved if all SUVs were replaced with SUVs using this design. Assumes SUV registrations will grow from 20 million in 2000 to 35 million over the next 5-10 years.
- Lifetime fuel cost based on: average gasoline price of \$1.40 per gallon; 15-year average vehicle lifetime; annual mileage of 15,600 in the first year, declining by 4.5% per year; and real discount rate of 5% (equivalent to an 8% new car loan). On-road fuel economy assumed to be 18% lower than CAFE test value.
- Lifetime global warming gas emissions presented as carbon dioxide equivalent emissions from the vehicle tailpipe (19 pounds/gallon) and from gasoline manufacturing and delivery (5 pounds/gallon). Emissions from manufacturing, refrigerant leaks, and other sources are not included. Emissions are based on the same vehicle lifetime and mileage estimates used to calculate lifetime fuel cost.
- The increase in the vehicle's retail price (excluding tax, title, and destination charges) due to the addition of fuel economy or safety technology.
- The difference in lifetime fuel cost relative to the baseline Ford Explorer.
- The time it takes for the additional cost of fuel economy improvements to be offset by fuel savings, assuming a 5% discount rate.
- Payback drops to 1.9 years and 5.3 years for the UCS Guardian and UCS Guardian XSE respectively if the costs and benefits of safety technologies are included (based on NHTSA's estimated economic cost of \$1 billion per fatality and an additional \$1 billion for injuries associated with each fatality). Assumes 35 billion SUV registrations.

with the Explorer engine, for a price increase of about \$415 (in 2002 dollars).

The test weight of the UCS Guardian is 4,100 pounds, 10 percent lower than the Explorer. This is achieved by using unibody construction techniques and moderate use of higher-strength steel. This lower weight takes into account a 17- to 20-pound increase due to the added safety features described below.

The U.S. steel industry's Light Truck Structure study demonstrated the potential of unibody construction to be employed at no cost or even a cost savings back in 1997 (AISI, 1997), and the technology is now being used in a limited number of SUVs including the Jeep Grand Cherokee and Honda Pilot. By switching to unibody construction and higher-strength steel, the UCS Guardian improves fuel economy by eight percent over the Ford Explorer.

In addition, lowering the vehicle and incorporating a smoother shape improves its aerodynamics. Combined with the use of lower rolling-resistance tires and improvements to some of the auxiliary systems, improved aerodynamics produces a fuel economy benefit of approximately six percent, at a cost of about \$185 (in 2002 dollars).

All together, these improvements result in a total fuel economy improvement of 31 percent, enabling the UCS Guardian to achieve a CAFE test fuel economy of 27.8 mpg for a price increase of \$600¹² (Table 1). Even at a conservative gasoline price of \$1.40 per gallon, the fuel economy improvements would pay for themselves in about two years, and the vehicle would save its owners more than \$2,500 on gasoline over its 15-year life.

Along with the fuel economy benefits come improved hill-climbing ability, or gradeability,

11 The EPA provides an adjusted fuel economy rating to consumers because the test used to determine CAFE fuel economy, developed in the early 1970s, no longer represents real-world driving. The EPA adjusts a vehicle's CAFE test results downward as follows: city rating by 10 percent; highway rating by 22 percent. These two ratings (as seen on a vehicle's window sticker) are combined, assuming the vehicle is driven 55 percent in the city and 45 percent on the highway.

12 Because of the synergies between the three fuel economy improvement techniques employed, the overall improvement is actually greater than the sum of the parts.

and the same acceleration as the Ford Explorer (as modeled). This is achieved despite using a smaller engine both because the vehicle is lighter and because variable valve technology provides more power for a given engine size. In this case, the new engine achieves 54 kW/liter, a 38 percent improvement in power, along with improved torque output for its size—an eight percent increase over the Explorer engine.¹³

Safety improvements. Among a host of safety technologies that could be included, we chose to incorporate the three most cost-effective into the UCS Guardian. In addition, the move to a lighter-weight, unibody construction for fuel economy purposes acts as a free safety feature for others on the road.

One of the simplest and most effective safety measures for vehicle occupants in all types of crashes is the use of a seat belt. Despite the fact that state laws require seat belt use, NHTSA's 2002 Annual Assessment indicates that nearly 60 percent of all occupant fatalities that year occurred in vehicles where the seat belts were not used (NHTSA, 2003b).

Current seat belt reminder systems are clearly not effective enough and can be replaced with better reminders that induce seat belt use in all but the most stubborn occupants.¹⁴ The Guardian includes improvements to Ford's current system and extends the system to all passengers. For about \$25 and a few extra pounds, this system could cut SUV occupant fatalities in single-vehicle and two-vehicle accidents by about 23 percent if it raised seat belt use to 90 percent.

Once seat belts are actually worn, the most effective step in reducing rollover fatalities is to

eliminate or drastically reduce roof crush. This can be done in concert with a unibody design, effectively providing the occupants with a roll cage, similar in concept to what race car drivers use. A conservative estimate indicates that, for \$50 and about 15 pounds in added weight, stronger SUV roofs could cut SUV fatalities in single-vehicle and two-vehicle accidents by an additional 23 percent.¹⁵

Finally, the effectiveness of seat belts in roll-over accidents can be improved. Today's belts do not lock up in most rollovers because there is often no frontal impact in these crashes. Incorporating a rollover sensor that activates seat belt pretensioners can help keep occupants snugly in their seats and minimize partial ejection. This technology could reduce SUV fatalities by another 14 percent for about \$60 and an additional pound or two.

If all SUVs on the road incorporated these technologies, SUV occupant fatalities could be reduced by nearly 2,000 per year in the near future. Another 350 lives would be saved annually as a result of the lower weight and improved crash absorption capability of unibody construction, which reduce the SUV's aggressivity. Additional lives may be saved by the lower bumper height and smoother front contour, but the results of these aggressivity reduction measures have not been estimated.

THE UCS GUARDIAN XSE

The XSE version of the UCS Guardian provides additional improvements in both safety and fuel economy. All of the technologies and design techniques we selected are either available in mass-

produced vehicles today or have been announced for MY 2004 or 2005, though not all of them are available in the United States.

While many of these changes could be made in the next major redesign for most SUVs, others would have to wait for an additional design cycle. This package would therefore be available after the introduction of the UCS Guardian, or by MY 2013 or 2014 at the latest. Window curtain air bags and electronic stability control systems, however, are already available today and should be made available as options in the baseline UCS Guardian.

The fuel economy technologies in the Guardian XSE would add about \$2,300 to the vehicle price compared with the Ford Explorer, but would pay for themselves in 5.4 years at a conservative gas price of \$1.40 per gallon. Over the 15-year average life of the vehicle, these improvements would save owners more than \$4,300 in gasoline. The safety technologies in the Guardian XSE would cost consumers less than \$650 and would save more than 2,900 lives per year if all SUVs on the road incorporated them. A summary of the Guardian XSE's safety and fuel economy performance, along with the associated savings, is shown in Table 1 (p.13).

Fuel economy improvements. The UCS Guardian XSE incorporates a 170-horsepower, 2.3-liter, stoichiometric-burn gasoline direct injection (GDI) engine. GDI engines are often operated with excess air, improving efficiency but increasing NOx emissions. This engine avoids that tradeoff by operating most of the time with only the required amount of air, improving efficiency approximately 20 percent above the baseline vehicle at a price of \$470 (in 2002 dollars).

The test weight of the Guardian XSE is reduced to 3,150 pounds through significant use of advanced high-strength steel in the unibody and the addition of aluminum and other lightweight materials

elsewhere on the vehicle. This weight reduction takes into account the 17- to 20-pound increase resulting from the UCS Guardian safety improvements, plus an additional 35 pounds resulting from the added safety features described below. This strong, but lighter, body structure costs an additional \$1,000 and provides a 25 to 30 percent improvement in fuel economy compared with the Ford Explorer.

The Guardian XSE uses a six-speed automatic transmission that adds another gear and eliminates the inefficient "torque converter" currently used to connect the engine to the transmission gears. This transmission improves fuel economy over the five-speed automatic by about nine percent at no cost. Removal of the torque converter and other design simplifications reduce the number of parts comprising the transmission, thereby providing the fuel economy benefit for the same price—or even less.

Finally, the Guardian XSE incorporates a 42-volt integrated starter-generator (ISG) between the engine and transmission. Current SUVs waste 10 to 15 percent of the fuel they burn simply sitting at stoplights and in traffic with the engine idling. By eliminating much of this idling, and improving the efficiency of the electrical system, ISG technology will increase fuel economy by approximately 11 percent, at a cost of \$660 (in 2002 dollars). Some automakers are planning to market new vehicles equipped with ISGs as "hybrids," but the technology is really just an incremental change to a conventional vehicle.

All of these features, together with the enhanced aerodynamics and rolling resistance of the base model Guardian, result in a total fuel economy improvement of 71 percent compared with the Ford Explorer. The Guardian XSE achieves a CAFE test fuel economy of 36.3 mpg for a total price increase of \$2,315 (Table 1, p.13).

continued on p.18

¹³ Torque output is related both to a vehicle's acceleration and its towing capacity.

¹⁴ These systems sound an intermittent chime until all passengers are wearing their seat belts. Current systems turn off after a few minutes. If this is not sufficient, other methods can be employed with little added cost.

¹⁵ This is the sequential safety improvement assuming seat belt use at 90 percent.

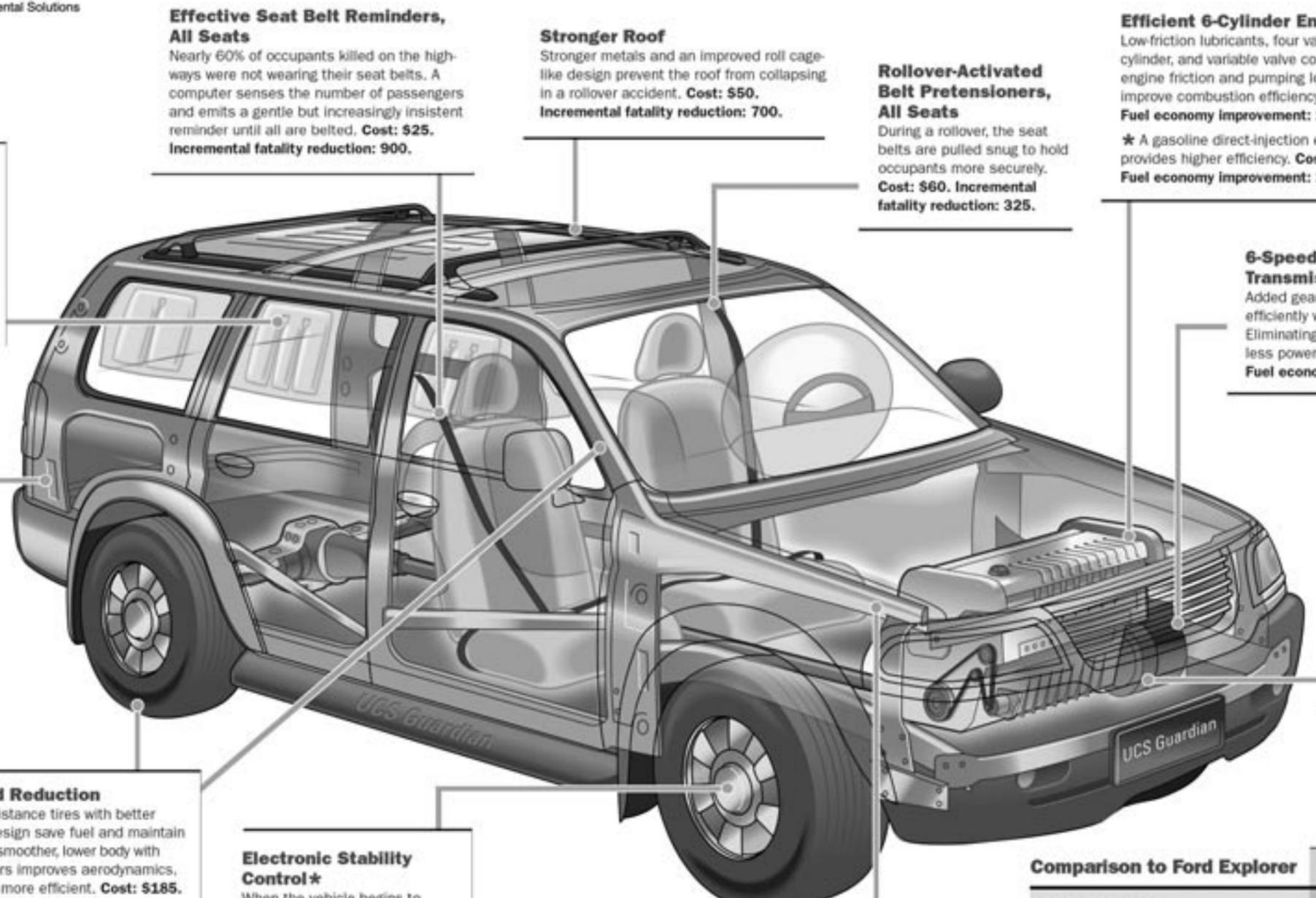


**Union of
Concerned
Scientists**

Citizens and Scientists for Environmental Solutions

THE UCS Guardian & Guardian XSE

A B L U E P R I N T F O R A B E T T E R S U V



**Window Curtain
Air Bags***

Stored above the vehicle's side windows, these air bags deploy in a side impact or rollover, protecting all occupants and keeping them inside the vehicle. **Cost: \$270. Incremental fatality reduction: 175.**

**Unibody Construction
& Better Materials**

A combined body and frame reduces the number of parts needed, saving money to pay for higher-strength steel that improves safety and reduces weight. **Cost: \$0. Fuel economy improvement: 8%. Incremental fatality reduction: 250.**

* Advanced high-strength steel and aluminum further reduce unibody weight while maintaining safety. **Cost: \$1,000. Fuel economy improvement: 25-30%. Incremental fatality reduction: >250.**

Vehicle Load Reduction

Lower rolling-resistance tires with better materials and design save fuel and maintain good traction. A smoother, lower body with redesigned mirrors improves aerodynamics. Accessories are more efficient. **Cost: \$185. Fuel economy improvement: 6%.**

**Effective Seat Belt Reminders,
All Seats**

Nearly 60% of occupants killed on the highways were not wearing their seat belts. A computer senses the number of passengers and emits a gentle but increasingly insistent reminder until all are belted. **Cost: \$25. Incremental fatality reduction: 900.**

Stronger Roof

Stronger metals and an improved roll cage-like design prevent the roof from collapsing in a rollover accident. **Cost: \$50. Incremental fatality reduction: 700.**

**Rollover-Activated
Belt Pretensioners,
All Seats**

During a rollover, the seat belts are pulled snug to hold occupants more securely. **Cost: \$60. Incremental fatality reduction: 325.**

Efficient 6-Cylinder Engine

Low-friction lubricants, four valves per cylinder, and variable valve control reduce engine friction and pumping losses and improve combustion efficiency. **Cost: \$415. Fuel economy improvement: 13%.**

* A gasoline direct-injection engine provides higher efficiency. **Cost: \$470. Fuel economy improvement: 20%.**

**6-Speed Automatic
Transmission***

Added gears help the engine operate more efficiently while providing plenty of power. Eliminating the torque converter means less power lost while driving. **Cost: \$0. Fuel economy improvement: 9%.**

**Integrated Starter-
Generator***

Allows the engine to shut off at stoplights and in stop-and-go traffic. Restarts the engine when you take your foot off the brake. **Cost: \$660. Fuel economy improvement: 11%.**

**Electronic Stability
Control***

When the vehicle begins to lose control or roll, this system reduces engine power and applies brakes on the appropriate wheels to compensate. **Cost: \$240. Incremental fatality reduction: 450.**

Front and Rear Crumple Zones & Lower Bumpers

Unibody construction absorbs more of the SUV's share of the crash forces, protecting occupants and others on the road. Lower bumpers help keep the SUV from riding up over other vehicles. **Cost: Included in unibody. Incremental fatality reduction: 100.**

For more information call (202) 223-6133
or visit www.suvsolutions.org

Prepared by:
Union of Concerned Scientists
and Center for Auto Safety

Revision No. 1

Sheet No. 1 of 1

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* Indicates features that are standard on the Guardian XSE model only.

Comparison to Ford Explorer	Guardian	Guardian XSE
Fuel Economy (Improvement)	27.8 mpg (31%)	36.3 mpg (71%)
Annual Lives Saved (All SUVs)	2,275	2,900+
Lifetime Fuel Cost Savings	\$2,502	\$4,383
Fuel Economy Technology Costs	\$600	\$2,315
Safety Technology Costs	\$135	\$ 645
Payback	2.1 years	5.4 years

Continued from p. 15

At a conservative gasoline price of \$1.40 per gallon, the fuel economy improvements would pay for themselves in 5.7 years. Over the course of the vehicle's lifetime, its owners would save about \$4,200 on gasoline—about twice the cost of the fuel economy improvements. And along with these benefits come improved hill-climbing ability (gradeability) and the same acceleration as the Ford Explorer.

Safety improvements. In addition to the safety features offered in the base model Guardian, the Guardian XSE includes two state-of-the-art technologies to further reduce rollover fatalities and provide added safety for others on the road.

The best way to avoid a rollover fatality is to avoid rolling over in the first place. The longer wheelbase and wider track of both Guardian models helps, and the Guardian XSE adds an electronic system to control the vehicle's stability and keep it from fishtailing in an emergency maneuver.

Different forms of electronic stability control are becoming optional on vehicles such as the Ford Explorer. However, optional components often come at inflated prices due to low or uncertain production volumes and added dealer mark-ups. The Guardian XSE comes standard with stability control at a cost of \$240. When added on top of the safety features of the base model Guardian, this technology can reduce fatalities by an additional 22 percent.

If the vehicle does roll over, additional protection beyond a stronger roof and better seat belts can be achieved with air bags that deploy across the vehicle's side windows. These window curtain air bags are activated by the same rollover sensor used for the seat belt pretensioners in the base model Guardian, and help reduce trauma by keeping occupants completely inside the vehicle. For an extra \$270, this technology reduces occupant fatalities an additional 11 percent.

The combination of safety improvements in the Guardian XSE could reduce SUV fatalities by about 2,550 per year in the near future if all SUVs on the road incorporated them. In addition, the Guardian XSE's lower weight would further reduce the SUV's aggressivity, although this improvement has not yet been evaluated.

Building Better Cars and Light Trucks

The majority of technologies UCS used to design a better SUV can also be incorporated into cars, minivans, and pickups as follows:

- Minivans are already among the safest vehicles on the road, but there is still potential to improve their fuel economy and save more lives. Previous estimates indicate that minivans could reach 30 mpg using the technology in the UCS Guardian, and more than 41 mpg using technology in the UCS Guardian XSE (An et al., 2002; DeCicco et al., 2001).
- Pickups typically share platforms with SUVs along with many of the same safety and fuel economy woes. Using technologies employed by the Guardian and Guardian XSE, pickups could reach 26 to 34 mpg or more while becoming much safer for drivers and others on the road (An et al., 2002; DeCicco et al., 2001).
- Many cars already incorporate some improved technology, and cars already weigh less than pickups and SUVs, but their fuel economy can still be improved to between 37 and 47 mpg (An et al., 2002; DeCicco et al., 2001). There is also plenty of room for improving car safety with more effective seat belt reminders and other technologies.

If all light trucks used the technology in the base model Guardian, their average fuel economy would increase to 27.5 mpg by MY 2008, cutting

Table 2 **Savings in 2015 from Fuel Economy Improvements**

	Light Trucks: 22.2 mpg by 2007 (NHTSA)	Light Trucks: 27.5 mpg by 2008	Car and Light Truck Average: 30 mpg by 2008	Car and Light Truck Average: 40 mpg by 2014
Oil Savings (millions of barrels per day) ^a	0.25	0.8	1.2	2.0
Gasoline Cost Savings (billions of dollars per year) ^b	\$5.3	\$17.6	\$26.2	\$43.7
Global Warming Gas Savings (million tons per year) ^c	45	150	225	375

NOTES:

a. Compared with a baseline scenario of no improvement in fuel economy. See appendices for modeling details.

b. Based on an average gasoline price of \$1.40 per gallon.

c. Global warming gas emissions presented as carbon dioxide equivalent emissions from the vehicle tailpipe (19 pounds/gallon) and from gasoline manufacturing and delivery (5 pounds/gallon). Emissions from manufacturing, refrigerant leaks, and other sources are not included.

U.S. oil use by 0.4 million barrels per day (mbd) in 2010 and 0.8 mbd in 2015. This is more than triple the savings that would result from NHTSA's 2005–2007 1.5-mpg light truck increase over the same timeframe.

Furthermore, raising the combined fuel economy of cars and trucks to 30 mpg by MY 2008 is not only possible using base model Guardian technology, but would also save 0.6 mbd in 2010 and 1.2 mbd in 2015. This is about five times the savings that would result from NHTSA's current fuel economy plans.

Putting Guardian XSE technology to work throughout the U.S. fleet of cars and trucks could result in an average fuel economy of 40 mpg by 2014—even if light truck sales increased to 60 percent of the light-duty vehicle market (an increase of 10 percentage points in market share over today). This would cut oil use by two million barrels per day by 2015.

Table 2 summarizes the annual savings that could be achieved under each of these fuel economy paths.

Future Trends

In 2002, the fuel economy of the average new passenger vehicle dropped to its lowest point since 1980 and highway fatalities reached their highest level since 1990. The question that remains is whether or not the next 10 to 20 years will con-

tinue these trends. The future of U.S. cars and trucks may be influenced—for better or worse—by several emerging vehicle technologies and trends, even if the technologies outlined in this report are put into place.

PICKUPS: THE NEXT SUV?

The first minivan was sold in 1983. In the decade that followed, sales went from zero to more than one million units. The next decade saw an explosion in SUV sales, reaching nearly one quarter of the passenger vehicle market by 2002. Will the next 10 years be the decade of the pickup?

This may seem far-fetched to those who view the pickup as a work vehicle, but the same was once said about vans and SUVs, which are now primarily used for hauling people. Large, six-passenger pickups with full-size beds are growing in popularity and have become one of the most profitable vehicles for automakers (Hakim, 2003). These models are replacing smaller three-passenger pickups and could be poised to duplicate the SUV growth of the 1990s.

Many of these large pickups are excluded from fuel economy standards. And, with nearly four times the aggressivity of the average midsize car, they are the most dangerous passenger vehicles to others on the road (Figure 7, p.10). Federal accident data and findings in a report by Ross and

Wenzel (2002) indicate that pickups are also among the most dangerous vehicles for the driver.¹⁶

Pickups must not be ignored when looking at improvements in vehicle safety and fuel economy. The improvements outlined in this report can be used to save lives and money while preserving performance for all those who choose pickups—whether they are used for work or for transporting passengers during the week and gardening on weekends.

CROSSING OVER

Another growing market segment is the so-called crossover vehicle, which includes vehicles such as the Subaru Forester, Chrysler Pacifica, Nissan Murano, Lexus RX330, and the upcoming Ford Freestyle. Though they are often referred to as light trucks, crossovers contain design elements of both cars and SUVs—they are effectively beefed-up, taller station wagons.

Built using unibody construction and offering all-wheel drive, crossovers generally weigh less than the average SUV and achieve better fuel economy. Early data also indicate that this type of vehicle tends to be safer, both for drivers and others on the road (Wenzel and Ross, 2003). As with all the other types of vehicles, crossovers that incorporate the technologies in the UCS Guardian would offer improved fuel economy and safety.

The influence crossovers will have on U.S. oil dependence and the environment will depend on what vehicles they replace. If they take the place of cars, crossovers will drive fuel economy and pollution trends in the wrong direction. If they replace future SUV sales, however, they can drive the trends in a positive direction. The outcome could be determined by the means with which automakers market these vehicles and by the way

government classifies them in fuel economy regulations.

HYBRIDS

The world started down a new road in 1997 when the first modern hybrid electric car, the Toyota Prius, was sold in Japan. The Prius was soon followed by the Honda Insight and Honda Civic Hybrid. These vehicles mark a radical change in the type of car being offered to the public: vehicles that bring some of the benefits of battery-electric vehicles to the conventional gasoline-powered cars and trucks the world has been using for more than 100 years.

Recent analysis indicates that a hybrid SUV would reach 42 to 49 mpg, depending on the technology used (Friedman, 2003). This hybrid relies on much of the same conventional technology in the Guardian XSE, plus an electric motor and battery system that would add \$1,000 to \$2,000 to its price when the vehicle is in mass production. However, the increased price also provides drivers with the added benefits of better acceleration from stoplights and more onboard electrical power.

Ford and GM have both announced hybrid versions of their smaller SUVs, and Toyota is introducing hybrid versions of its Lexus RX330 crossover and Highlander midsize SUV. Although not actually hybrid technology, GM and Daimler-Chrysler have announced the availability of ISGs on some of their future cars and trucks.

Early hybrids will be more expensive to make due to their low production volumes and the technology's lack of maturity. However, around the time the Guardian XSE could be available, hybrid technology could also be a standard option in the showroom for all vehicles. Its success will

be significantly influenced by government support and how automakers choose to market the vehicles.

For example, if the government provides performance-based tax credits to stimulate the adoption of clean, efficient hybrids, and automakers market these vehicles effectively, production volumes will rise and prices will drop. This would translate into more choices for consumers and more assurance that cars and trucks could average even better than 40 mpg by 2014. Without government incentives and automaker commitment to hybrids that provide significant improvements in fuel economy and emissions in the early years, hybrid technology will remain a novelty with little impact on the world.

MISUSED TECHNOLOGY

The technologies incorporated into the UCS Guardian and UCS Guardian XSE can turn around current safety and fuel economy trends, but only if they are actually used to achieve those goals.

The 2003 Honda Pilot is a good example of how technology can be used in a way that fails to live up to its potential.¹⁷ The Pilot has a 240-horsepower, 3.5-liter, single overhead cam V6 engine (Honda, 2003) that incorporates four valves per cylinder, low friction, and variable valve technology to achieve a specific power of about 51 kW/liter—a significant improvement over the Ford Explorer engine. However, despite this improved engine, a more efficient four-wheel drive system, and significantly better aerodynamics, the Pilot only manages a 22-mpg CAFE fuel economy rating compared with 27.8 mpg for the UCS Guardian and 20 mpg for the V6 four-wheel drive Explorer.

The Honda Pilot suffers from poor fuel economy because it weighs as much as the Ford Explorer despite its unibody frame, and because it

out-accelerates the Explorer V6 by about 1 to 1.5 seconds (0-60 mph time). In fact, the Pilot even beats the bigger V8 Explorer's 0-60 mph time by about half a second (Heraud, 2003; Consumer Guide, 2003).

Thus, while Honda has shown that these fuel economy technologies are here today, it has disappointingly put them to work primarily to provide even greater acceleration in a heavy vehicle. Today's SUVs already have plenty of power, performance, and room. What they don't have is better fuel economy, lower gasoline bills, fewer heat-trapping emissions, and improved safety. This is where the technologies in the blueprint for the UCS Guardian and UCS Guardian XSE can be put to their best use.

Conclusion: Building a Better Future

For the past 15 to 20 years, automakers have focused on building bigger and more powerful cars and trucks, and consumers now have vehicles with plenty of size and hauling power. But they also have vehicles that fail to provide the safety and fuel economy Americans want and deserve.

With the technologies described in this report, automakers can spend the next decade and beyond focused on saving thousands of lives and billions of dollars at the pump every year. The UCS Guardian and UCS Guardian XSE provide a blueprint for a better SUV that can deliver these benefits without forcing consumers to sacrifice the size and performance they have today. The technology exists today; automakers just have to put it to work.

¹⁶ The risk to the pickup driver and passengers is influenced both by a propensity to roll over and a greater degree of driving on rural roads.

¹⁷ Although the Honda Pilot does not make full use of its fuel economy technology, it is lower and wider than the Ford Explorer, reducing rollover risk. Front and rear crush zones also help absorb more of the dangerous forces in an accident, but the Pilot does not provide many of the other safety technologies discussed in this report.

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Appendix A TECHNOLOGY PACKAGE SUMMARY

The table below provides a summary of the technologies used in each fuel economy package for this report. A further description of the fuel economy technologies can be found in Appendix C. A further description of the safety technologies can be found in Appendix D.

The fuel economy benefits are presented as the percent improvement over the baseline SUV. Simple addition or multiplicative summation of

the benefits will not yield the same results as the systems-based modeling results used in this report.

The safety benefits are presented as marginal improvements in the order listed, assuming all SUVs incorporate this technology. In other words, the fatality reduction from improved roof support already assumes the use of a more effective seat belt-use reminder. These values cannot be used separately.

Table A-1 **Modeled Fuel Economy and Safety Improvements with Associated Costs**

	Fuel Economy Improvement vs. Baseline	Marginal Fatality Reduction ^a (All SUVs)	Cost (2001\$)	Baseline SUV	Guardian	Guardian XSE
Fuel Economy Technology						
Vehicle Load Reduction ^b	6%		\$185		X	X
10% Weight Reduction (Unibody Construction, Stronger Steel)	8%	see below	\$0 or cost reduction		X	
30% Weight Reduction (Unibody Construction, Advanced High-Strength Steel & Aluminum)	25%-30%	see below	\$1,000			X
<hr/>						
Baseline SOHC, 2-Valve Engine				X		
Low-Friction, VVC, DOHC, 4-Valve Engine	13%		\$415		X	
Stoichiometric Gasoline Direct Injection Engine	20%		\$470			X
42-Volt Integrated Starter-Generator, Idle Off, and Torque Smoothing	11%		\$660			X
<hr/>						
Baseline 5-Speed Automatic Transmission, Torque Converter				X	X	
6-Speed Automatic Transmission, No Torque Converter	9%		\$0 or cost reduction			X
Package Fuel Economy Improvement					31%	71%
Safety Improvements						
Effective Seat Belt-Use Reminders		900	\$25		X	X
Improved Roof Support		700	\$50		X	X
Rollover-Activated Belt Pretensioners		325	\$60		X	X
Electronic Stability Control System		450	\$240			X
Rollover-Deployed Window Curtain Air Bag		175	\$270			X
Reduced Weight (see above)		250	\$0 ^c		X	X
Front and Rear Crumple Zones, Lower Bumpers		100	\$0 ^c		X	X
Package Fatality Reduction (All SUVs)^a					2,275	2,900+

NOTES:
a. SUV registrations climb from 20 million to 35 million over the next 5-10 years. Assumes all SUVs incorporate the technology.
b. 10% reduction in aerodynamic drag, 20% reduction in rolling resistance, electric power steering.
c. These safety improvements come along with the fuel economy improvements listed above.

Appendix B

MODELING METHODOLOGY AND ASSUMPTIONS

Vehicle Fuel Economy Model

Unlike many major fuel economy assessments, we apply a system simulation approach to evaluate the fuel economy potential of the various technologies in this report. This approach includes the use of the Modal Energy and Emissions Model (MEEM) to evaluate technology packages applied to a set of vehicles representing the major U.S. light-duty vehicle classes.

MEEM provides a physical representation of vehicle systems, avoiding double-counting while also teasing out the synergies that exist between the various technologies. MEEM has been extensively reviewed and applied for vehicle fuel consumption and transportation air quality analyses; its results for conventional vehicles are consistent with those of other simulation tools such as the Department of Energy’s ADVISOR model (An, 2001a; An, 2002b).

Stock Model

To evaluate the oil savings for the conventional vehicle scenarios, we developed and calibrated a stock model covering the period 2000 to 2030. This model uses the annual sales and fuel economy of new vehicles, along with other key input data, to predict annual fleet gasoline and oil use.

We calibrated our baseline model against the *Annual Energy Outlook 2001* (AEO) report by the Energy Information Administration (EIA, 2000). Annual fleet energy use is kept to within ±2.5 percent of the AEO results, using its new vehicle fuel economy values as inputs. However, we assume no increase in fleet fuel economy based on the past 15 years of declining average fuel econo-

my, whereas the EIA assumes future fuel economy increases resulting from economic forces. Additional details on this stock model are available in the appendices of Friedman, 2001.

Vehicle sales projections. Car and truck sales data for 2000 to 2020 are based on EIA, 2001. Sales from previous years are based on Ward’s, 2000. Sales data for individual vehicle types were estimated based on current vehicle trends.

Vehicle-miles traveled as a function of vehicle age. The 1995 National Personal Transportation Survey provides the most recent breakdown of vehicle mileage versus age. The vehicle mileage used in our model is a simplified version of those data, using 15,600 miles as the distance driven the first year, declining at a rate of 4.5 percent per year as used in the recent National Research Council CAFE report (NRC, 2002).

Vehicle Economic, Fuel Use, and Emission Model

The economic, fuel use, and emission modeling in this report was performed using the following data and assumptions.

Fuel economy and safety technology costs. Analyses from DeCicco et al., 2001 and NRC, 2002 formed the basis for various fuel economy component costs in this report. Cost data have been updated to 2002 dollars where necessary.

The costs of the rollover-sensitive seat belt pretensioners, electronic stability control system, and window curtain air bags are based on analysis of similar systems in the Volvo XC90 performed for the Center for Auto Safety and UCS by Anil Khadilkar. The authors estimated the costs

of the more effective seat belt reminders and stronger roof.

All cost data assumed mass production of components as standard equipment with production of at least 300,000 units per year. All costs are represented as the retail price increase to the consumer and include the cost of materials, labor, and markups to account for engineering and design, manufacturer profits, dealer margins, overhead, marketing, etc.

Car and light truck lifetime. Data in Davis, 2002 suggest that the median life of a model year (MY) 1990 car is 16.9 years, while the median life of an MY 1990 light truck is reported to be 15.5 years. Combined data suggest a median lifetime of more than 16 years for MY 1990 cars and light trucks. For simplicity, we have assumed a 15-year vehicle life.

EPA Adjusted vs. CAFE test fuel economy. The fuel economy test procedure was developed about 20 years ago and no longer represents real-world driving conditions. Values for the relative difference between real-world and CAFE fuel economy for conventional vehicles in EIA, 2001 vary between 17 and 19.6 percent, depending on the year.

Automakers still comply with CAFE standards based on this outdated test. However, the Environmental Protection Agency (EPA) assumes a gap of about 15 percent (10 percent for city driving and 22 percent for highway driving) for the fuel economy values that appear on vehicle window stickers. We have adopted the EPA methodology here when citing the EPA Adjusted fuel economy, but provide the CAFE numbers for comparison with existing standards. The EPA Adjusted fuel economy figure still falls short of the difference between test and real-world driving conditions. Therefore, we use an 18 percent gap when calculating lifetime fuel costs and savings, similar to EIA findings.

Annual average gasoline cost. Average gasoline costs are based on EIA, 2001 and have been con-

verted to 2002 dollars. The average value during the period from 2000 to 2020 in EIA, 2001 is \$1.40, which is used here. Given recent trends, these costs are probably low and can therefore be considered conservative.

Discount rate. All future costs and savings are discounted at a real rate of five percent. This corresponds to a new car loan of eight percent and inflation of three percent. All costs are presented in 2002 dollars.

Emission rates. The emission rates used for global warming gases associated with gasoline production and delivery (so-called upstream emissions) are based on the latest available version of a model developed by Argonne National Laboratory, GREET 1.5a (Wang, 1999). The model uses average national emission rates and efficiencies to estimate emissions of key pollutants throughout the fuel cycle for various types of gasoline and alternative fuels. This report assumes that federal reformulated gasoline is used nationally, since

Table B-1 **Fatality and Registration Data (2000)**

Crash Mode ^a	Fatalities in: ^b			
	Cars	SUVs	Pickups	Vans
Single-Vehicle, Non-Rollover				
	4,762	495	1,429	401
Rollover				
First Event	1,395	1,055	1,021	301
Subsequent Event	2,477	642	1,060	253
Two-Vehicle Crashes				
Car/Car, SUV/SUV, etc.	3,311	93	430	91
Car/SUV	1,190	253		
Car/Pickup	2,371		573	
Car/Van	925			259
SUV/Pickup		190	211	
SUV/Van		89		95
Pickup/Van			202	193
Registered Vehicles (millions)^c	127.7	19.1	38.9	18.2

NOTES:
a. Fatalities in accidents with pedestrians, motorcycles, bicycles, large trucks, or more than two vehicles have been excluded.
b. Fatality data for 2000 from the Federal Accident Reporting System (FARS).
c. Registration data for 2000 from The Polk Company.

Table B-2 **Fatality Reduction from Technologies Adopted in All SUVs**

	Crash Type ^a				Total
	Single-Vehicle, Non-Rollover	Rollovers		Two-Vehicle Crashes	
		First Event	Subsequent Event		
Estimated Future SUV Fatalities ^b	700	1,400	950	900	3,950
SUV Occupant Fatality Reduction^c					
Effective Seat Belt-Use Reminders	200	250	200	250	900
Improved Roof Support		450	250		700
Rollover-Activated Belt Pretensioners	75	100	75	75	325
Electronic Stability Control System	75	200	100	75	450
Rollover-Deployed Window Curtain Air Bag	50	75	50		175
Non-Occupant Fatality Reduction					
Reduced Weight				250	>250
Front and Rear Crumple Zones, Lower Bumpers				100	100
Total Fatality Reduction	400	1,075	675	750	>2,900

NOTES:
 a. Fatalities in accidents with pedestrians, motorcycles, bicycles, large trucks, or more than two vehicles have been excluded.
 b. Assumes SUV registrations rise from about 20 million to 35 million over the next 5–10 years.
 c. SUV occupant fatality reductions apply only in the order shown.

environmental rules are forcing more conventional gasoline blends out of the market.

REET accounts for several global warming gases including methane, nitrous oxide, and carbon dioxide, expressing the results as CO₂-equivalent emissions, based on their relative radiative forcing. The model also accounts for key criteria emissions associated with air pollution, including the volatile organic compounds and nitrogen oxides (smog precursors), carbon monoxide, sulfur oxides, and particulate matter.

Based on the aforementioned calculations and modeling, we developed average per-gallon emissions of global warming gases as follows: tailpipe—18.7 pounds (8.5 kg) per gallon of gasoline; upstream activities—5.3 pounds (2.4 kg) per gallon of gasoline; for a total of 24 pounds (10.9 kg) per gallon.

Safety Model

Fatality reductions were estimated based on current fatality rates in single-vehicle and two-

vehicle accidents. Accidents with pedestrians, motorcycles, bicycles, large trucks, or more than two vehicles have been excluded. Fatality data are based on information from the Federal Accident Reporting System for the year 2000. Registration data are based on information from The Polk Company for the year 2000.

Fatalities in single-vehicle crashes are assumed to be proportional to the number of vehicles of that type in operation at the time. Fatalities in two-vehicle crashes are assumed to be proportional to the product of the number of each vehicle type involved (fatality rate equals the number of fatalities in a given vehicle divided by the product of the numbers of that type of vehicle on the road and the number of the type with which it collided). For crashes between like vehicles, the square of the number of vehicles registered is used. Table B-1 (p.27) provides a summary of the year 2000 vehicle crash statistics used in this report. SUV registrations are assumed to grow to 35 million vehicles over the next 5 to 10 years.

Current seat belt usage in fatal accidents is less than 50 percent. Improved seat belt reminders are assumed to increase seat belt use to 90 percent. Reductions in fatalities for all occupant safety technologies are based on the design improvements incorporated and are a function of the order of application (i.e., the life savings are marginal values) and the crash type. Driver behavior, driver demographics, road type, driving location, and other

factors can affect the final effectiveness of these technologies. These issues were not considered in this report due to increasing evidence that the design of the vehicle and associated safety features are a dominant factor in fatality rates (Wenzel and Ross, 2003).

Table B-2 provides a summary of the fatality reductions in various crash modes for each technology used in this report.

Appendix C

FUEL ECONOMY TECHNOLOGY

The Evolution of Conventional Technology

Although automobiles have seen more than 100 years of development, more can still be done to improve their efficiency. These changes in technology represent an evolutionary path and include many technologies that are either on the road today in the United States in smaller volumes or can be found on the road in other parts of the world. These technology options can be split into three categories: load reduction, engine improvements, and transmission improvements.

VEHICLE LOAD REDUCTION

When a car or truck drives down the road, its engine has to provide enough power to overcome three obstacles that try to keep it from moving (not counting potholes).

First, the vehicle has to provide enough power just to get its 1.5 to 2.5 tons of metal, plastic, and glass rolling; the faster it tries to accelerate, the more power it has to provide. Then, the instant the vehicle starts moving, the tires grab onto the road and produce friction that requires additional energy to overcome. Further, as the vehicle gains speed, it has to push more and more air out of the way, which causes an aerodynamic drag effect.

To make matters worse, additional power is drawn from the engine for accessories such as air conditioning, power steering, lights, air circulation, and any electronic equipment plugged into the car outlet. However, several technology approaches can reduce all of these loads and thereby reduce the fuel needed to drive down the road.

Mass reduction. The first step to reduce the mass of SUVs is a switch to unibody construction. SUVs and pickup trucks are typically built using body-on-frame construction. This technique uses a heavy steel body bolted to stiff frame rails. All cars and minivans have abandoned this construction technique in favor of unibody construction.

Unibody construction replaces the separate body and frame with a single unit. This new body/frame unit can be lighter than the body-on-frame design. It is also very stiff around the passenger compartment for safety and incorporates crush space in the front and rear of the vehicle to absorb much of the impact in a crash.

The manufacturing process for a unibody is a bit more complicated, but has become commonplace over the past two decades. Also, unibody construction reduces the number of parts needed to make the vehicle and ensures that the unibody frame is no more expensive, or even less expensive, than the old body-on-frame construction.

The next step to reduce mass is the substitution of lower-strength steel with high-strength steel and aluminum. The steel industry has investigated lightweight car and truck designs through its UltraLight Steel Auto Body and Light Truck Structure studies (AISI, 1997; AISI, 2001; ULSAB, 2001a; ULSAB, 2001b).

The unibody design for the first SUV in the Light Truck Structure study was estimated to cut its number of parts compared with body-on-frame construction by 32 percent, reduce its weight by 19 percent, and save 20 percent on the cost. In addition, the crash-worthiness of these vehicles

was evaluated through computer simulations and was shown to be equal or superior to current standards.

Mass reductions of up to 40 percent have been demonstrated in production and prototype vehicles that rely on aluminum and other lightweight materials for much of the powertrain, vehicle structure, and body. While these lighter vehicles do carry additional costs, they are designed to maintain safety, strength, and durability (Ford, 2001).

Aerodynamics. Today's cars look a lot different from those of 10 or 20 years ago. Their bodies are defined by more curves, windshields are more slanted, and the front grilles are almost invisible. These new shapes are a combination of style and functionality, since the drag that a vehicle feels from the wind is a function of both its frontal area and a shape factor called the coefficient of drag (C_D).

The C_D of today's cars is around 0.30 to 0.35, while that of light trucks is around 0.40 to 0.45 (DeCicco et al., 2001). The difference between the two should not be too surprising when one compares the tall, wide, and flat front of a truck with the front of today's cars. In both cases, however, improvements can be made to reduce the aerodynamic drag. Various studies have estimated that the C_D of cars can be reduced by 10 to 25 percent, while the C_D of light trucks could drop by about 10 percent (DeCicco and Ross, 1993; EEA, 1991; NRC, 1992). In addition, Honda has recently demonstrated superior low-drag performance for its Honda Pilot, with a C_D of 0.36 (Heraud, 2003).

Tires. The stickiness of a tire on the road is measured by its coefficient of rolling resistance (C_{rr}). The value of the C_{rr} indicates the pounds of resistance created by the tires based on the vehicle's mass. A typical estimate of today's rolling resistance is 0.009, indicating that 0.9 pounds of resistance

are created for every 100 pounds of vehicle mass. Rolling resistance can be reduced both by making the vehicle lighter and by using better tires.

Improving the efficiency characteristics of the tires requires the use of improved rubber, increased inflation pressures, and changes in tread design. Estimates show that such changes can reduce the C_{rr} by 15 to 30 percent without compromising vehicle handling and safety (DeCicco et al., 2001).

EFFICIENT ENGINES

At the heart of most cars and trucks is an internal-combustion engine that burns gasoline to produce the power required to overcome the vehicle load and make the vehicle move. The problem with these engines is that the vast majority of the energy in the gasoline is turned into wasted heat—only 20 to 25 percent of the energy can be used to move the vehicle down the road under typical driving conditions. As with vehicle loads, however, technologies exist to improve the efficiency of the internal-combustion engine.

Improved conventional engines. Internal-combustion engines have seen continuous evolution over the 125 years since the technology was first developed. The basic workings of the spark-ignition engine, however, have not radically changed. What have changed are the myriad detailed components and designs that can have a significant impact on engine efficiency.

Some of the most recent advances are combined in the Honda VTEC engine. The key characteristics of the engine are the use of variable valve control (VVC), four valves per cylinder, aluminum as a major engine component, reduced friction, and improved intake and exhaust designs. Some versions of the VTEC engine also use a reduced idle speed to minimize the amount of fuel wasted when the vehicle is sitting in traffic.

According to one measure of an engine's efficiency, the VTEC-E engines used by Honda are more than 15 percent more efficient than the average car engine and more than 25 percent more efficient than the average engine in all passenger vehicles.¹ Just as impressive as the engine efficiency is the fact that the VTEC line of engines is used in more than 80 percent of the cars and trucks Honda sells in the United States.

Direct-injection gasoline engines. The cars and trucks of the 1970s used a carburetor to mix air and gasoline together before they entered the cylinder to be burned. This method of mixing was not very efficient and made it difficult to control the amount of fuel being introduced.

Over the past 30 years, fuel injection has been introduced and is now the standard. Fuel injection sprays fuel into the air just before the air enters the cylinder and allows for more precise metering of the fuel as well as the production of smaller drops that mix more easily with the air. The fuel spray is constrained by the amount of time the valve is open, however, and by the timing of the opening, making the control better than with a carburetor but not ideal.

The next evolution of the internal-combustion engine is the use of direct-injection technology. Direct injection sprays fuel directly into the cylinder at high pressure. This allows for more fine-tuned control of the amount of fuel injected and injection timing that is independent of valve timing. These engines can still use variable valve control and four valves per cylinder as the VTEC engines do, but will achieve even higher efficiencies. Overall, these engines show both higher efficiency and a broader range of operating conditions under which their efficiency maintains reasonable levels.

Some versions of gasoline direct-injection (GDI) engines operate in a "lean" mode where excess air is provided. This helps improve the efficiency of the engine even further, but makes it very difficult for today's emission control systems to reduce the amount of nitrogen oxides—a key pollutant in the formation of smog—emitted by the vehicle. Until "lean-NOx" emission control systems can be adequately developed, GDI engines will have to avoid lean operation to ensure that public health is protected and that current and future emissions standards are met.

Integrated starter-generators. When you ask people how fuel-efficient their cars are, they will likely tell you how many miles they can travel per gallon of fuel. This is a great measure for the average efficiency of a car. But when you are sitting in traffic or at a stoplight, your engine is running but you are going nowhere; your miles-per-gallon rating at that time is zero. Depending on driving conditions, 10 to 15 percent of the fuel Americans put in their tanks is used up during these idling conditions.

The problem for today's vehicles is that it is not convenient to turn off your car when you are stuck in traffic or sitting at a light. Within the next few years, however, many of the major automobile manufacturers are expected to introduce cars that will shut off instead of idle and then automatically start up and move as soon as the gas pedal is pressed.

This feature requires the use of a small motor/generator that will be attached directly to the engine. The "integrated starter-generator" will replace both the current starter motor and the alternator, and will even enable some of the energy in the battery to be tapped by contributing a small burst of power when the car first starts moving.

Integrated starter-generator (ISG) systems will be operated at 42 volts instead of using the 12-volt systems of today's cars. This added power will allow automakers to run accessories such as power steering and air conditioning off the electricity supplied by the ISG instead of being driven by belts connected to the engine—belts that waste energy via friction. The 42-volt ISG systems will also increase the efficiency of any other system or accessory that typically runs at 12 volts.

IMPROVED TRANSMISSIONS

The function of the transmission is to take the power generated by the engine and transfer it to the axle in order to drive the wheels and move the car down the road. The simplest and most efficient way to accomplish this would be to use a single gear between the engine and the axle. This system is not possible with the engines in today's cars, however.

Current internal-combustion engines can operate only within a limited speed, and at very low speeds, the engine produces very little torque. Furthermore, there is an even smaller operating window outside of which the efficiency of the engine is relatively poor. To account for this limitation, transmissions use several gears to allow the vehicle both to accelerate quickly and travel at high speeds, while also attempting to keep the engine operating within a relatively efficient window.

The vast majority of transmissions in vehicles today are "automatic" transmissions, which take the burden of shifting between gears off the driver. Accomplishing this requires complex and inefficient hydraulic systems. Typical automatic transmissions are about 80 percent efficient; when combined with the average efficiency of a gasoline internal-combustion engine, only 15 to 20 percent of the energy ever reaches the wheels.

Five- and six-speed automatic transmissions. The typical way transmissions have been used to

improve a vehicle's efficiency is by adding more gears. Since 1980, nearly all of the automatic transmissions in cars and trucks have been converted from three speeds to four. The additional gear means the engine can spend more time operating in the speed and torque ranges where it is most efficient and powerful.

The late 1990s saw the initial introduction of five-speed automatic transmissions. Again, this added speed increases the opportunities for the engine to run near its "sweet spot" and achieve a higher overall average efficiency. Only about 20 percent of today's cars and light trucks use five-speed automatic transmissions, so there is great potential for this technology to spread. The next step would be to introduce six-speed versions, though many automakers are considering moving right from four-speed automatics to six-speed automatics.

An additional step that can be taken to improve the efficiency of these transmissions is to eliminate the inefficient torque converter. The torque converter is a hydraulic version of the clutch used in a manual transmission. When you first start to move a car with manual transmission, you ease in the clutch, letting it slip so the engine will not stall. The torque converter does the same thing and, at low speeds, provides greater torque multiplication at the wheels.

However, because the torque converter is a fluid coupling, it is very inefficient. New six-speed transmissions are being developed using sophisticated computer controls that allow for smooth starting and shifting without the torque converter. Plus, the additional gears allow you to make the first gear ratio larger, providing good starting torque. The efficiency of this system approaches that of a manual transmission without the need to shift gears yourself.

Continuously variable transmissions. Going further than five or six speeds in a conventional

¹ Specific power measures how effective an engine is at producing power given its size; this can be used as one indication of engine efficiency. The Honda VTEC-E achieves a specific power of 54 kW/liter (Honda, 2003) compared with the average car and light truck specific power of 43 kW/liter (DeCicco et al., 2001) and the average car specific power of 46.9 kW/liter (EPA, 2000).

automatic transmission introduces added weight and complexity and is probably not worth the effort. There is significant benefit, however, to going “all the way” and having an infinite number of gears.

This may seem impossible, but a technology called the continuously variable transmission (CVT) allows for an infinite number of variations in gear between minimum and maximum levels. With this infinite variation, the engine speed and torque can be chosen to maximize engine efficiency over a much wider range of operation than with conventional multispeed transmissions.

Several manufacturers are currently offering CVT versions of their cars and small SUVs, and several more are expected to do so in the near future. The Honda Civic HX and Civic Hybrid have been available with a CVT for the last several years. Audi has offered a CVT version of its A6 since 1999 and even boasts that this model has superior performance to both the automatic and manual transmission models (www.schwab-kolb.com/audi/pr47.htm). General Motors offers a CVT in its small SUV, the Saturn Vue.

The main weakness of the CVT in the past was its inability to work in anything but very small cars. This limitation has been overcome for cars, but the CVT does still have torque limitations that make it unclear how widespread its use can be with larger light trucks.

“Automatic” manual transmissions. The advantage of a manual transmission over an automatic

is that the use of inefficient hydraulic controls is not required when the driver does the shifting. The simplicity of manual transmissions translates into operating efficiencies in the mid-90 percent range, compared with the low 80 percent range for automatics.

The disadvantage of the manual transmission is that the driver is required to put forth more effort and attention, especially in increasingly congested driving conditions. Over the past 10 to 15 years, the inconvenience of the manual transmission has caused its use to drop in half, from about 25 percent to about 10 percent of car and light truck transmissions.

An alternative to the standard manual transmission is an automated manual transmission that uses small electric motors to shift gears at the command of a computer control system. The intent of this system is to combine the convenience of the automatic transmission with the efficiency of the manual.

Various versions of this technology have made small penetrations into the market, primarily in sports cars. The main concern is whether these systems can mimic the relatively smooth shifting of an automatic and still maintain their performance. With continued development, these transmissions may be an excellent alternative to five- and six-speed automatic transmissions for light trucks.

Appendix D SAFETY TECHNOLOGY

Safety Improvements for SUVs

The two key concerns about SUV safety are rollovers and the dangers they pose to others on the road. Existing technologies can be used to address both of these problems. Some of these technologies are already available as options on some vehicles, but they need to become standard features to both save more lives and bring down the cost.

COUNTERMEASURES THAT REDUCE THE LIKELIHOOD OF A ROLLOVER

The most critical factor leading to a rollover is a vehicle’s tendency to oversteer and yaw so that it begins to slide laterally. A vehicle’s weight distribution, tires, tire pressure, and suspension characteristics can all contribute to this tendency.

Manufacturers could increase the understeering tendencies of their vehicles with changes in vehicle geometry, suspension, and tires. However, a heavily understeering vehicle tends to feel unresponsive to more aggressive drivers. Because of this, manufacturers tend to minimize understeer, and thus make their vehicles more vulnerable to oversteer under certain circumstances. Furthermore, even a vehicle that understeers under normal conditions may oversteer if it is full of passengers and luggage.

Modifying suspension geometry. Changes in suspension geometry (and possibly more sophisticated suspension systems including such features as independent rear suspension) can reduce the likelihood of oversteer. Minor changes include

tuning the anti-roll bars that are often part of the vehicle’s suspension and changing the roll centers (the points at which the vehicle rotates about a longitudinal axis due to suspension geometry) of the front and rear suspension systems. Depending on the aggressivity of these changes, they can reduce oversteer without moving to an understeering vehicle.

Widening and lowering the vehicle. An alternative approach is to reduce the chance that an oversteering SUV will tip over once it is moving sideways. Designing an SUV with a wider track (the lateral distance between the wheels) and a lower center of gravity is a very inexpensive way to reduce its tendency to roll over. The SUV may still oversteer, but once it is moving sideways, it will be less likely to roll.

Every inch that a vehicle’s center of gravity is lowered (and every two inches its track is widened) increases its static stability factor (SSF) by about four percent. According to data from NHTSA, for vehicles in the SSF range of SUVs (two to three stars for an SSF of 1.04 to 1.24), an increase in SSF of around eight percent decreases the rollover probability by at least 25 percent.¹ Thus, lowering the center of gravity by one inch and increasing the track width by two inches (one inch on each side) should reduce the rollover probability of a fleet of such vehicles by approximately 25 percent.

Widening a vehicle can be done for no cost if it is performed during its regular four- to six-year

¹ An increase in SSF from two stars (average SSF = 1.08) to three stars (average SSF = 1.18), a nine percent increase, reduces the probability of a rollover from 30 to 20 percent, a 33 percent decrease.

redesign process. But even before that takes place, offset rims can stretch out the tires to make the vehicle more stable (though at a cost to aerodynamic drag).

Lowering a vehicle can also be achieved at zero cost through changes to the suspension and smaller tires. Adjustments to the suspension include four-wheel independent suspension and changes to suspension geometry that result in lower ride height. These changes do not have to compromise off-road capability for those who actually use this feature in SUVs. Adjustable-height suspension systems can be made available when purchasing an on/off-road SUV package.

Computer control. Instead of reducing a vehicle's oversteering characteristics, a potentially more satisfactory approach is to implement an electronic (anti-yaw) stability control, or ECS, system that counteracts oversteer. Mercedes-Benz introduced these systems several years ago and they are becoming available on a wider selection of more expensive vehicles, including Ford's Volvo XC90.

ECS systems are built on top of anti-lock braking systems and use computer controls to apply or release the brakes on different wheels to keep the vehicle from fishtailing. This can dramatically reduce an SUV's tendency to yaw in an emergency maneuver.

COUNTERMEASURES THAT PROTECT OCCUPANTS IN A ROLLOVER

The two factors associated with most severe rollover occupant injuries are occupant ejection and roof crush. These problems are associated with the two major design deficiencies in SUVs today: a lack of effective seat belts and seat belt use, and a weak roof that both crushes down on occupants and leads to broken windows, allowing passengers to be partially or fully ejected.

Effective belt-use reminders. Since fewer than half of all people involved in rollovers are belted,

vehicle features that encourage belt use are the most critical factors for reducing rollover casualties (and crash casualties in general). These features include belts that are comfortable and convenient to use, and effective belt-use reminders. Since laws throughout the United States require belt use, effective belt-use reminders should not be a problem for any but the most recalcitrant non-users.

Belt-use reminders would have only a nominal cost for the sensors and electronics involved, and should have an effectiveness of raising belt use in SUV rollovers to between 80 and 90 percent. The National Academy of Sciences is currently studying the issues involved in incorporating more effective seat belt-use reminders such as electronic devices that emit more urgent, repeated warnings as a vehicle continues to be operated with unbelted occupants. This would not only reduce ejection in rollovers by 30 to 40 percent, it would improve safety in other crash modes.

Improving comfort and convenience involves better placement of belt mountings and modifying retractor spring tension. These steps would also increase belt use for no extra cost. Seat mountings (as opposed to mountings on the B pillar of the vehicle), for example, place the belt where it can be more easily reached, and the belt can be made to fit better around the occupant. The extra cost of mounting seat belts in outboard front seats (and of the strengthened seats required for such mounting) would be at least partly offset by the savings in structural mountings. Note that Chevrolet has used such systems in its basic full-size pickup trucks for several years, suggesting both practicality and a nominal cost penalty.

Rollover-activated belt pretensioners. A secondary problem with most seat belts is that their retractors do not remain locked throughout a rollover. Seat belt pretensioners triggered by rollover sensors are the most effective means of ensuring

good restraint during a rollover. Pretensioners are currently installed in most new cars (General Motors is the one significant holdout in not making pretensioners standard equipment except in a few of its models). Thus, the primary extra cost for these systems would be for rollover sensors.

Less expensive (but less effective) systems include cinching latch plates that do not permit webbing from the lap portion of the belt to become slack even if the retractor locking mechanism fails to hold the shoulder belt. Improved retractor lockup mechanisms (that respond to omni-directional forces and remain locked throughout a rollover) would also improve belt performance. These items require only a minor redesign that would have little cost impact.

Improved roof support. Today's SUV roofs often collapse during a rollover accident because of the following deficiencies: roof materials that are too thin or weak to provide structural integrity; non-boxed structural members such as roof pillars, side rails, and windshield headers; holes in critical structural members; inadequate gussets connecting roof pillars, rails, and headers; and inadequate welds in roof structures.

Eliminating these problems (and keeping the vehicle's roof from contacting an occupant's head with a force greater than roughly four times the person's weight or at a closing speed greater than 7 to 10 miles per hour) would virtually eliminate the head and neck injuries associated with rollovers (Friedman and Nash, 2001; Friedman and Nash, 2002). In a rollover, the roof typically strikes the ground at a vertical velocity of less than five miles per hour, so the conditions that would protect the head and neck in a rollover by preventing the roof from collapsing or buckling are relatively easy to meet.

Minor roof design improvements to eliminate these defects would have virtually no cost implications. These design changes should have little

or no impact on cost or weight if manufacturers incorporate them at the time they redesign their vehicles.

Using additional steel or stronger steel (such as high-strength, low-alloy steel or boron steel) in the roof structure along with overall improved design would substantially improve a roof's ability to resist collapse and buckling during a rollover.

Rollover-deployed window curtain air bags. A feature that should reduce head injuries and partial ejections in rollovers is window curtain air bags with rollover sensors. These air bags are stored along the roofline of the vehicle and are triggered when the vehicle rolls. They deploy along the length of the driver and passenger side windows, protecting all occupants.

Ford is currently offering this system as an option in its Explorer and Expedition models, and it comes standard in Ford's Volvo XC90. As with all of these safety technologies, the costs are significantly inflated when they are only offered as options, thus reducing their use and the number of lives that can be saved. These systems need to be standard on all SUVs for their full effectiveness to be achieved.

COUNTERMEASURES TO IMPROVE THE SAFETY OF OTHERS WHO SHARE THE ROAD WITH SUVs

The aggressivity of SUVs and other light trucks is a function of three factors: weight, stiffness, and height.

The average weight of all SUVs on the road is well over 1,000 pounds greater than the average weight of passenger cars. Because momentum is conserved in a collision, the lighter vehicle will be forced to experience a greater change in velocity in a crash than a heavier one. The greater the weight disparity, the more severely will the occupants of the lighter vehicle experience the crash. This is sometimes misinterpreted as implying that heavier vehicles are safer; however, if the lighter

of the two vehicles is made heavier, the overall crash forces increase, making it a deadlier crash for everyone.

The structures of SUVs are substantially stiffer than passenger car structures. Most SUVs that are built on light truck chassis have this structural stiffness concentrated at the ends of their frame rails. It has long been understood that because heavier vehicles experience less velocity change in a crash and are usually larger than lighter vehicles, they should absorb more of the crash energy by being less stiff. Truck-based SUVs seriously violate this principle, and force the passenger cars they hit to absorb most of the crash energy. This means that in more severe crashes, the cars suffer substantial deformation of the passenger compartment and more intrusion when they are hit by SUVs.

The height of the principal structural elements of an SUV is at least several inches above that of passenger cars. The consequence is that SUVs often ride up over a passenger car's structural elements that are designed to protect the vehicle and its occupants. This increases intrusion into the car's passenger compartment and injuries to the occupants.

Improved compatibility and reduced SUV aggressivity in two-vehicle crashes can be achieved by addressing each of these factors.

Reducing weight. Weight reduction can be achieved with material substitution and more effi-

cient design. These changes may have modest or zero cost implications in a new vehicle if combined with a switch to unibody construction, and could save money on gasoline by improving fuel economy, as described in Appendix C.

Many competitive smaller SUVs are already built on passenger car platforms or with unibody construction, but could still take advantage of lighter materials. Very few midsize SUVs use unibody construction and all could benefit from lighter materials.

Reducing stiffness. Employing unibody construction along with front structures that are designed to collapse in an accident while keeping the passenger compartment safe are the key to reducing the stiffness of SUVs. This is actually very similar to race car design, where much of the front or rear of the car breaks up while the driver is kept safe in a safety cage.

These front structures should also be designed to be safer for pedestrians (i.e., a smoother front with geometry that can reduce the severity of head impacts, and front surfaces that are softer and yield more when striking a pedestrian).

Lowering the SUV. Techniques to lower the SUV have already been discussed in respect to reducing rollovers. These have the added benefit of offering the proper height to engage passenger car structures rather than riding up over them.