The UCS Vanguard

A Vehicle to Reduce Global Warming Emissions Using Today's Technologies and Fuels

SPENCER QUONG

Union of Concerned Scientists
March 2007

Spencer Quong is a senior analyst in the UCS Clean Vehicles Program.

The Union of Concerned Scientists is the leading science-based nonprofit working for a healthy environment and a safer world.

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

To learn more about UCS and the Clean Vehicles Program, or to download the full text of this report, visit the UCS website at *www.ucsusa.org/clean_vehicles*.

Printed on recycled paper

Contents

Tables

Acknowledgements

Spencer Quong is the primary author of this report. Louise Bedsworth, now of the Public Policy Institute of California, researched and wrote several sections on component technologies. Patricia Monahan, Don Anair, Erin Rogers, and David Friedman of UCS also contributed to the research and reviewing of this report.

UCS would like to thank Jason Mark for his technical contributions, and The Energy Foundation for its financial support. The Union of Concerned Scientists is solely responsible for the content of this report.

Executive Summary

California has taken a groundbreaking step in confronting climate change by enacting a law to reduce global warming emissions from vehicles. The law sets ambitious fleet-wide emission targets for new vehicles beginning in 2009, based on studies by the California Air Resources Board (ARB) on the effectiveness of various technologies in cutting emissions. Many of these technologies are already a reality: numerous vehicle models on the road today use at least one of them.

Engineers at the Union of Concerned Scientists (UCS) have taken the ARB analysis one step further and created a blueprint for vehicles that would reduce global warming emissions even more dramatically. The result: the UCS Vanguard minivan, the first design that combines climate-friendly automotive technologies with the use of biofuels in one vehicle. Indeed, our analysis shows that use of the Vanguard technology package in all classes of vehicles, including the largest trucks and sport utility vehicles, can reduce global warming emissions by 43 percent, without sacrificing performance or safety.

Even more striking, the Vanguard approach is cost-effective. In fact, our analysis reveals that, consumers will see an overall drop in operating costs over the lifetime of Vanguard vehicles (based on retail fuel prices in October 2006). And drivers would begin to reap these savings in only one to five years. That is partly because the cost of incorporating cleaner technologies and allowing vehicles to run on alternative fuels is modest. Indeed, many vehicles now on the road can burn ethanol as fuel.

The bottom line is that automakers can produce vehicles now that dramatically reduce global warming emissions. What is more, the availability of numerous cleaner technologies—and the ease of enabling vehicles to run on alternative fuels—give automotive manufacturers many options to choose from.

CHAPTER 1

THE IMPETUS FOR THE VANGUARD

In 2002 the California legislature passed Assembly Bill 1493—commonly known as the Pavley law for its sponsor, Assemblywoman Fran Pavley—which calls for achieving "the maximum feasible and cost-effective reduction of greenhouse gas (GHG) emissions from motor vehicles." In response, the California Air Resources Board (ARB) launched a study to examine technologies that could help fulfill that goal. The resulting report and subsequent addendum is known as ISOR, for *Initial Statement of Reasons for Proposed Rulemaking, Public Hearing to Consider Adoption of Regulations to Control Greenhouse Gas Emissions from Motor Vehicles* (ARB 2003a; ARB 2003b).

In that report, the ARB found that the use of better technologies could reduce heat-trapping emissions from new passenger cars and small trucks by an average of 34 percent, and emissions from medium-sized trucks by an average of 25 percent. These cuts in emissions would occur from the baseline year of 2009—when near-term targets begin to take effect under the Pavley law—to 2016, when automakers must meet mid-term emission targets. The report also found that the costs to consumers of these emission-reducing technologies would be modest (see Table 1).

UCS resolved to take the ARB analysis one step further by examining the impact of combining emission-cutting technologies with the use of fuel composed of 85 percent ethanol and 15 percent gasoline. To estimate the impact on global warming emissions of this fuel—known as E85—we relied on adjustment factors developed by the ARB that account for lifecycle emissions from E85: that is, from the "well to the wheel."

Our findings are striking: we found that the use of advanced technologies available today combined with alternative fuels can provide an effective and low-cost approach to cutting global warming emissions by more than 40 percent. In fact, this approach would not only curb emissions significantly but also save consumers money over the lifetime of their vehicles.

Table 1: Average Emission Targets for New Vehicle Fleets and Estimated Costs to Comply with California's Pavley Law

	Passenger Car/ Light-Duty Truck 1 ≤3,750 lbs.		**Light-Duty Truck 2 3,751–8,500 lbs.**	
	Allowable New Fleet Average Emissions (g CO_2-eq/mi)	% Reduction from 2009 Baseline	Allowable New Fleet Average Emissions (g CO_2-eq/mi)	% Reduction from 2009 Baseline
Near Term				
2009	323	1.3%	439	2.1%
2010	301	4.4%	420	5.5%
2011	267	14.0%	390	11.8%
2012	233	24.9%	361	18.3%
Additional vehicle cost to meet near-term standard		***$367***		***$277***
Mid-Term				
2013	227	26.7%	355	19.6%
2014	222	28.5%	350	20.9%
2015	213	31.2%	341	22.9%
2016	205	33.9%	332	24.8%
Additional vehicle cost to meet mid-term standard		***$1,064***		***$626***

Source: Air Resources Board 2002.
g CO_2-eq/mi = grams of carbon dioxide equivalent per mile.

CHAPTER 2

EMISSION REDUCING AUTOMOTIVE TECHNOLOGIES

In its study, the ARB examined cleaner and more efficient technologies for major automotive components, including engines, transmissions, electrical systems, vehicle load reduction, air conditioning, and fuels. The agency evaluated these technologies based on:

- potential reductions in global warming emissions;
- time to market;
- manufacturing cost; and
- ability to work with other components.

All of the technologies that the study examined are already in use in vehicles on the market today (see Appendix).

Engine Technologies

The basic combustion process entails mixing fuel and air in a chamber or cylinder, and combusting the mixture with a spark plug or other ignition source. Engineers have developed numerous technologies to boost the efficiency and power output and lower emissions from engines, including microprocessor-based controls. Several technologies achieve these results by controlling the amount of fuel and air entering the cylinder more precisely.

For example, technologies that inject gasoline directly into the combustion chamber rather than farther upstream can improve the engine’s throttling efficiency and power output. A *stoichiometric direct injection system*—already in vehicles today—uses the exact ratio of air and fuel to complete the combustion process without any remaining constituents, which might increase emissions.

Valves on each cylinder open and close to allow fuel and air to enter and exit the combustion chamber. Depending on demand for power, an advanced engine can actively vary the lift—that is, the size of the valve opening—to alter the amount of fuel and air entering the chamber, making the engine more efficient. In a *discrete variable valve lift system*, the engine controller can change the valve opening by a few fixed increments. In a *continuous variable valve lift system*, the engine controller can adjust the valve opening by varying amounts. The engine can also vary the length of time the valves are open and closed in response to driving conditions. The cam synchronizes the timing of the valves on all the cylinders, and newer engines use *coupled* or *dual cam phasers* to modify this timing. The well-known Honda VTEC engine uses both variable valves and timing.

By controlling valves individually, an engine equipped with *cylinder deactivation* can disable some cylinders when it does not need their added power, such as when the vehicle is cruising on the highway. The engine uses all the cylinders when the driver wants to accelerate rapidly or haul heavy loads, and modern engine controls provide a seamless transition between the different modes. Some larger vehicles and trucks sold in the United States—including the Chevy Suburban and GMC Yukon—now use this technology.

A *turbocharger* uses heat from a vehicle's exhaust to compress the air entering the engine, boosting its power output. This allows the use of smaller engines with fewer global warming emissions. Turbochargers appear on many different vehicles produced today.

Transmission Technologies

A vehicle's transmission transfers power from the engine to the wheels, and allows the driver to select different gear ratios, similar to gears on a bicycle. Adding more gears allows the engine to operate near its peak efficiency a greater percentage of the time, and ensures a smoother ride.

A traditional automatic transmission uses a torque converter, which allows the engine to spin independently of the transmission and wheels when needed, similar to the clutch in a manual transmission. A torque converter is a fluid coupling that uses a pump and transmission fluid to transfer engine rotation to the wheels. An *automated manual transmission* replaces the torque converter with an electronically controlled clutch mechanism, which combines the smooth functioning of an automatic transmission with the efficiency of a manual transmission.

Vehicle Electrification

A vehicle's electrical system also provides an opportunity to reduce emissions. Replacing mechanical components, such as power steering and air conditioning, with electrical components—which are more energy-efficient—can reduce engine load, directing more energy to the wheels and cutting global warming emissions. Coupling this electrification with a high-efficiency advanced alternator can reduce global warming emissions even further.

Load Reduction

The size and profile of a vehicle determines the ease with which it moves through the air—that is, its ability to overcome drag. Redesigns of some vehicles have reduced their aerodynamic drag by as much as 15 percent (An et al. 2002).

Energy losses from rolling resistance through the tires are significant for any vehicle. Tires with low rolling resistance—which are available on many new vehicles, and to some extent on the secondary market—reduce this loss, and the load on the vehicle. Modifying the composition of tires, such as by using more silica, can further reduce rolling resistance, and thus reduce global warming emissions (Friedrich 2003).

Advanced Air Conditioning

Air conditioning systems contribute to global warming emissions from vehicles through direct emissions—those from the air conditioning system itself—and indirect emissions, which stem from greater load on the engine. Refrigerants containing hydrofluorocarbons (HFC) have a global warming potential that is many times greater than that of carbon dioxide.

Enhanced HFC-134a System

The use of better hoses and connections can substantially reduce direct emissions of HFC-134a from air conditioning systems (Fernqvist 2003). The use of more efficient compressors, such as fixed or variable displacement compressors (FDC or VDC), along with more effective condensers, and other system improvements, can reduce indirect emissions (Bhatti 1998). One analyst at the European Union’s Mobile Air Conditioners Summit in 2006 estimated that such an enhanced system could reduce direct emissions from HFC-134a by up to 50 percent, and curb indirect emissions by as much as 25 percent. The cost of such a system appears to be similar to or lower than that of alternative refrigerants (Pettersen 2003).

Alternative Refrigerant: HFC-152a

HFC-152a appears to be a very promising replacement refrigerant in the near term. The transition from one HFC to another would be fairly easy because similar components could be used, and because HFC-152a has a much lower global warming potential (120 times more potent than carbon dioxide) than HFC-134a (1,300 times more potent). Furthermore, direct CO_2-equivalent emissions of refrigerant from a 152a system can be reduced by 95 percent or more compared with a baseline 134a system because of the smaller amount of refrigerant needed, lower leak rate, and lower global warming potential. Indirect CO_2–equivalent emissions can be reduced by up to 10 percent (Hill 2003).

In the ISOR study, the ARB estimated the direct and indirect reduction in global warming emissions that would result from upgrading the air conditioning system in the near term and mid-term (see Table 2).

Table 2: Reduction in Global Warming Emissions from Advanced Air Conditioning Systems

	Indirect CO_2-Equivalent Reduction from Advanced AC VDC system (g/mi)[1]	**Direct CO_2-Equivalent Emission Reduction (g/mi)**		**Total A/C System Reduction (g/mi)**[4]	
		Near-Term[2]	Mid-Term[3]	Near-Term	Mid-Term
Small Car	7.1	3.0	8.5	10.1	15.6
Large Car	8.1	3.0	8.5	11.1	16.6
Minivan	10	3.0	8.5	13.0	18.5
Small Truck	10	3.0	8.5	13.0	18.5
Large Truck	10	3.0	8.5	13.0	18.5

Source: Air Resources Board 2002.

Notes:
1=Improved efficiency air conditioning VDC or FDC system; 2=Improved low leak HFC 134a system; 3=Improved low-leak HFC 152a system; 4=Sum of direct and indirect emission reduction credits

VDC=variable displacement compressor; FDC=fixed displacement compressor

Alternative Fuels

California's Pavley law allows manufacturers to receive credit for vehicles that use alternative fuels with lower lifecycle emissions from the well to the wheels. The ARB calculated a fuel cycle emission ratio for different fuels, based on the ratio of CO_2–equivalent emissions from the well to the pump relative to the CO_2-equivalent emissions from the tailpipe.

For example, while exhaust emissions from E85 are similar to those of gasoline, the fuel cycle emission ratio for E85 is lower, because growing corn removes carbon dioxide from the atmosphere, creating negative upstream emissions (see Table 3).

The ARB then used the fuel cycle emission ratio to calculate a CO_2 adjustment factor for each fuel. Calculating the equivalent CO_2 emissions for an alternative-fueled vehicle requires simply multiplying the CO_2

tailpipe emissions by the CO_2 adjustment factor of the alternative fuel. In doing that calculation, the ARB estimates that the use of 85 percent corn-based ethanol instead of gasoline can reduce global warming emissions by about 26 percent. To qualify for the adjustment factor, the automotive company must certify that the vehicles use only the alternative fuel during their entire lifetime.

Table 3: Fuel Cycle Emission Ratio and Adjustment Factor for Fuels

Fuel	Fuel Cycle Emission Ratio (upstream g CO_2/ exhaust g CO_2)	CO_2 Adjustment Factor: Ratio to RFG (g CO_2 alternative Fuel/ g CO_2 RFG)
Reformulated Gasoline (RFG)	0.31	1.00
Compressed Natural Gas (CNG)	0.35	1.03
Liquid Propane Gas (LPG)	0.17	0.89
E85 (corn)	-0.04	0.74

Source: Air Resources Board 2002.

According to the ARB, the incremental cost of converting a vehicle to ethanol is negligible, because almost all components designed for use with gasoline are compatible with ethanol. In fact, more than 30 vehicle models sold in 2007 can run off a range of gasoline/ethanol mixtures, and these vehicles cost the same as gasoline-only versions. DaimlerChrysler, Ford, and GM say that half of the vehicles they manufacture in 2012 could run off ethanol (MSNBC News Service 2006).

Technology Packages

The ARB developed baseline (2009), near-term (2012), and mid-term (2016) technology packages that would be available on most vehicles in five categories: small car, large car, minivan, small truck, and large truck.

To analyze the impact on global warming emissions of these packages, combined with the use of corn-based E85 fuel, UCS selected one package from each size category, and analyzed its emission performance and cost-effectiveness. In doing so, we added ethanol to the near-term packages developed by the ARB, and deliberately chose packages that together represent most of the technological options considered by the ARB (see Table 4).

Table 4: Technologies in Baseline and Selected Near-Term Packages

	Baseline	Near-Term Technology Packages Evaluated
Small Car	Discrete variable valve lift Dual cam phasing 5-speed automatic transmission	Discrete variable valve lift Dual cam phasing Automated manual transmission Electric power steering Improved alternator Advanced air conditioning Load reduction 85% ethanol (E85)
Large Car	Discrete variable valve lift Dual cam phasing 6-speed automatic transmission	Continuous variable valve lift Dual cam phasing Automated manual transmission Electric power steering Improved alternator Advanced air conditioning Load reduction 85% ethanol (E85)
Minivan	Discrete variable valve lift Coupled cam phasing 5-speed automatic transmission	Stoichiometric gasoline direct injection Dual cam phasing Turbocharging Automated manual transmission Electric power steering Improved alternator Advanced air conditioning Load reduction 85% ethanol (E85)
Small Truck	Discrete variable valve lift Dual cam phasing 6-speed automatic transmission	Cylinder deactivation Discrete variable valve lift Coupled cam phasing Automated manual transmission Electric power steering Improved alternator Advanced air conditioning Load reduction 85% ethanol (E85)
Large Truck	Coupled cam phasing 6-speed automatic transmission	Cylinder deactivation Discrete variable valve lift Coupled cam phasing Automated manual transmission Electro-hydraulic power steering Improved alternator Advanced air conditioning Load reduction 85% ethanol (E85)

Source: Air Resources Board 2002.

The ARB modeled the emissions of the baseline vehicle in each category with and without various near-term and mid-term technology packages, including advanced air conditioning and using gasoline as a fuel. The ARB also estimated the incremental cost of these technology packages (see Table 5).

Table 5: Emissions from Baseline and Selected Near-Term Vehicles and Associated Costs

Vehicle Class	Emissions from Baseline Vehicle (g CO_2-eq /mi)	Emissions from Gasoline Vehicle with Near-Term Technology Package (g CO_2-eq /mi)	Incremental Cost over Baseline Vehicle (in 2006 dollars)
Small Car	285	223	$180
Large Car	323	255	$543
Minivan	371	287	$299
Small Truck	405	318	$298
Large Truck	484	386	$670

Source: Air Resources Board 2002.
g CO_2-eq /mi = grams of carbon dioxide equivalent per mile.

CHAPTER 3

CALCULATING THE LIFETIME EMISSIONS AND COSTS OF USING CLEANER TECHNOLOGIES WITH ETHANOL

In this section, we use the results developed by the ARB and shown in Table 5 to calculate emission reductions from the use of E85 with the near-term technology packages. To do so, we multiplied the results by the ethanol adjustment factor in Table 3 (p. 8). In calculating the emission benefits of combining low-cost, cleaner, off-the-shelf technologies with the use of ethanol, we averaged emissions from small and large cars, and also averaged emissions from small and large trucks. (This approach does not factor in the current or projected fleet mix, but is intended to provide representative figures. The ARB also excluded minivans when calculating emissions targets.) <u>We found that the *near-term* technology package with E85 exceeds the *mid-term* Pavley targets for both fleets of vehicles</u> (see Table 6).

Table 6: Reductions in Global Warming Emissions from Vanguard Vehicles

Vehicle Class	Emissions from Vanguard Vehicle (Near-Term Technology Package with E85) (g CO_2-eq/mi)	% Reduction from 2009 Baseline Vehicle	Average Fleet Emissions (g CO_2-eq/mi)	Mid-Term Pavley Emission Target (g CO_2-eq/mi)
Small Car	165	-42%		
Large Car	188	-42%	177	205
Minivan	216	-43%		
Small Truck	233	-43%		
Large Truck	299	-42%	261	332

Note: g CO_2-eq/mi = grams of carbon dioxide equivalent per mile.

Lifetime Costs of Alternative Fuels

We then needed to analyze the lifecycle costs or savings from using E85, and add those to the incremental costs of using more advanced automotive technologies (Table 5, p. 10). Predicting the price of fuel is notoriously difficult: the cost of gasoline has almost doubled in the past five years, and it fluctuates greatly.

Therefore, to calculate the lifetime cost of using E85 versus gasoline, we used actual pump prices reported by the Department of Energy (DOE). The DOE's Energy Information Administration (EIA) reports weekly on the average price of gasoline at the pump from some 800 retail gas stations. We averaged the five weekly pump prices reported by the EIA in October 2006 for reformulated regular gasoline in California. The result was an average gasoline price of $2.55 per gallon (EIA 2006).

The DOE's Alternative Fuels Data Center (AFDC) collects retail prices for alternative fuels. However, the AFDC reported only two prices for E85 on the West Coast in October 2006, compared with 67 prices in the Midwest (AFDC 2006). Because of the small sample size, we used the average price of E85 at the pump in the Midwest from October 2006 ($1.97 per gallon), and added $0.14 per gallon for transporting that ethanol to the West Coast, based on an analysis by the EIA (EIA 2002).

The lifetime cost estimates of using cleaner technologies plus ethanol include the incremental cost of the vehicle (Table 5), less the cost savings from the use of cleaner technologies and E85. We calculated the savings over 16 years using a discount rate of five percent and fuel prices noted above). Table 7 shows annual vehicle miles traveled (VMT) over the 16 years, based on the ARB's Emissions Factor Model (EMFAC).

Table 7: Estimated Annual Miles Traveled over a Vehicle's Lifetime

Year	1	2	3	4	5	6
VMT	17,699	16,541	15,655	14,882	14,195	13,572
Year	7	8	9	10	11	12
VMT	12,999	12,469	11,974	11,510	11,074	10,663
Year	13	14	15	16	**Total**	
VMT	10,274	9,904	9,555	9,222	**202,189**	

Source: Air Resources Board 2002.

We found that besides providing major cuts in global warming emissions, vehicles in all classes would save consumers money over the lifetime of the vehicles (see Table 8). For example, a consumer would save $1,034 over the lifetime of a Vanguard minivan, and receive payback on the extra investment in the near-term technologies in less than two years.

Table 8: Lifetime Cost Savings from the Use of Near-Term Technology Packages and E85

Vehicle Class	Incremental Cost over Baseline of Near-Term Technologies (2006 Dollars)	Lifetime Consumer Savings (2006 Dollars)	Net Savings during Vehicle Lifetime (2006 Dollars)	Years to Break Even
Small Car	-$180	$809	$629	1.6
Large Car	-$543	$552	$9	5.2
Minivan	-$299	$1,333	$1,034	1.6
Small Truck	-$298	$1,317	$1,019	1.6
Large Truck	$670	$1,096	$426	3.7

Rebound Effect

A “rebound effect” occurs if people drive extra miles when their costs of operating a vehicle fall. In analyzing this potential effect, the ARB found that a 25 percent decrease in operating costs would spur consumers to increase the number of miles they drive by just 0.32 percent in 2020, and by 0.14 percent in 2030. This rise in VMT would be negligible because operating costs are only one factor affecting people’s decisions on how many miles to drive—other influences include time, traffic, and other transportation options.

Estimating the Cost of Automotive Components

The costs of the vehicle components the ARB cited are based on interviews with automotive experts and manufacturers. The ARB assumed that manufacturers will produce 500,000 units of these components annually for several years in a competitive environment.

Automotive manufacturers have often commented that the ARB’s cost estimates are not realistic. However, as noted, all the technologies are already available in vehicles today. What is more, the Pavley law does not prescribe which technologies manufacturers must incorporate into their vehicles. Rather, the law assumes that manufacturers will find the most cost-effective approach to reducing global warming emissions.

The Sensitivity of E85 Lifecycle Emissions

The method used to produce ethanol from corn does affect the amount of global warming gases that are emitted into the atmosphere. Researchers at the University of California Berkeley who evaluated six studies of such emissions found a wide range of results—from a 20 percent increase to a 32 percent decrease in lifecycle emissions of ethanol versus gasoline. Overall, the researchers estimated that the production and use of corn ethanol reduces global warming pollution by an average of 18 percent. However, if the promise of ethanol made from cellulose rather than corn becomes reality, emissions from ethanol could fall by as much as 88 percent (Farrell et al. 2006).

To take this range of potential outcomes into account, we analyzed two alternative scenarios for emissions from Vanguard vehicles. First, we reduced the CO_2 adjustment factor from 0.74—as calculated by the ARB—to 0.86, a more conservative number (see Table 9). Second, we also used a more optimistic adjustment factor of 0.61, to reflect the potential reduction in global warming emissions that would result from greater use of cellulose-based ethanol.

Table 9: The Impact of Different Lifecycle Assumptions on Emissions from Vehicles with Vanguard Technology Package

	Conservative Lifecycle CO_2 Emissions Adjustment Factor = 0.86		Optimistic Lifecycle CO_2 Emissions Adjustment Factor = 0.61	
Vehicle Class	Emissions from Vanguard Technology Package with E85) (g CO_2-eq /mi)	% Reduction from 2009 Baseline Vehicle	Emissions from Vanguard Technology Package with E85) (g CO_2-eq /mi)	% Reduction from 2009 Baseline Vehicle
Small Car	194	-32%	136	-52%
Large Car	222	-31%	155	-52%
Minivan	250	-33%	175	-53%
Small Truck	277	-32%	194	-52%
Large Truck	336	-31%	235	-51%
Note: g CO_2-eq /mi = grams of carbon dioxide equivalent per mile.				

As expected, these changes affect the global warming emissions from the vehicles. However, in the conservative case, emissions from small and large Vanguard trucks (using near-term technologies and E85) still meet the mid-term Pavley targets. And Vanguard cars and minivans are within 10 percent of the mid-term Pavley goals.

Still, enabling manufacturers and consumers to fulfill these goals through the use of Vanguard vehicles will require expanding the infrastructure for corn-based ethanol. The realization of advanced technologies such as cellulose-based ethanol will also prove critical to providing the quantity of alternative fuels needed to support large number of vehicles using E85, ensuring widespread cuts in global warming emissions from vehicles.

The Bottom Line on the Vanguard Technology

Our analysis shows that the use of ethanol along with off-the-shelf emission-reducing technologies can cut global warming emissions from vehicles by up to 43 percent. This combination also saves consumers money over the lifetime of their vehicles, with a payback period of one to five years. And an analysis by the ARB shows that consumers will increase the number of miles they drive by less than 1 percent in response to lower operating costs from the use of these advanced technologies.

Even conservative estimates of lifecycle global warming emissions from the use of ethanol show a substantial drop over those from gasoline. Many vehicles on the road today can already use ethanol, and equipping all vehicles to use such alternative fuel would not be costly. Fully realizing the promise of ethanol, however, will require greatly expanding its availability, and further research on advanced processes for producing it from cellulose.

Many technological options are available today to reduce global warming emissions from vehicles. All the emission-cutting components we considered appear in vehicles now on the road. The fact that these cleaner components are already in use suggests that manufacturers would find it cost-effective to incorporate them into all their vehicles.

References

Alternative Fuels Data Center. 2006. *Clean Cities Alternative Fuel Price Report*. Washington, DC: U.S. Department of Energy. October. Available online at *http://www.eere.energy.gov/afdc/resources/pricereport/price_report.html*

An, F., D. Friedman, and M. Ross. 2002. *Near-Term Fuel Economy Potential for Light-Duty Trucks.* Warrendale, PA: Society of Automotive Engineers, 2002-01-1900. June.

Bhatti, M.S. 1998. *Global Warming Impacts of Automotive Air Conditioning*. Warrendale, PA: Society of Automotive Engineers, 982929. November.

California Air Resources Board (ARB). 2003a. *Initial Statement of Reasons for Proposed Rulemaking, Public Hearing to Consider Adoption of Regulations to Control Greenhouse Gas Emissions from Motor Vehicles*. Sacramento, CA. August.

California Air Resources Board (ARB). 2003b. *Addendum Presenting and Describing Revisions To: Initial Statement of Reasons for Proposed Rulemaking, Public Hearing to Consider Adoption of Regulations to Control Greenhouse Gas Emissions from Motor Vehicles*. Sacramento, CA. August.

Energy Information Administration (EIA). 2006. *U.S. Retail Gasoline Prices.* Washington, DC: U.S. Department of Energy. October. Available online at *http://www.eia.doe.gov/oil_gas/petroleum/data_publications/wrgp/mogas_home_page.html*.

Energy Information Administration (EIA), Office of Integrated Analysis and Forecasting. 2002. Review of Transportation Issues and Comparison of Infrastructure Costs for a Renewable Fuels Standard. Washington, D.C. September. Available online at *http://www.eia.doe.gov/oiaf/servicerpt/fuel/pdf/question3.pdf*.

Farrell, A., R. Plevin, B. Turner, A. Jones, M. O'Hare, and D. Kammen. 2006. *Ethanol Can Contribute to Energy and Environmental Goals*, *Science* 311(5760): 506–508.

Fernqvist, H. 2003. *Fuel Efficient, Leak Tight HFC-134a Systems through Design and Quality Components*, presented at the MAC Summit, Brussels. February 11. Available online at *http://europa.eu.int/comm/environment/air/mac2003/pdf/fernqvist.pdf*.

Friedrich, A. 2002. *Fuel Savings Potential from Low Rolling-Resistance Tires*, presented at the California State Fuel-Efficient Tire Program Workshop, Sacramento, CA. September.

Hill, W.R. 2003. *HFC152a as the Alternative Refrigerant*, presented at the MAC Summit, Brussels. February 11. Available online at *http://europa.eu.int/comm/environment/air/mac2003/pdf/hill.pdf.*

MSNBC News Services. 2006. Bush tells auto leaders "tough choices" ahead: Execs from GM, Ford Chrysler meet with President to outline concerns. November 14. Available online at *http://www.msnbc.msn.com/id/15702310.*

Pettersen, J. 2003. *Pros and Cons of the Options: Improved 134a, HFC-152a, and CO2 (R-744)*, presented at the MAC Summit, Brussels. February 11. Available online at *http://europa.eu.int/comm/environment/air/mac2003/pdf/pettersen.pdf*.

APPENDIX

2007 MODELS USING AT LEAST ONE COMPONENT FEATURED IN VANGUARD VEHICLES

Flexible Fuel

Buick Terraza
Dodge Caravan
Dodge Durango
Dodge Ram Pickup
Chevrolet Avalanche
Chevrolet Express
Chevrolet Impala
Chevrolet Monte Carlo
Chevrolet Silverado
Chevrolet Suburban,
Chevrolet Tahoe
Chevrolet Uplander
Chevrolet Van
Chrysler Aspen
Chrysler Dakota
Chrysler Durango
Chrysler Sebring
Ford Crown Victoria
Ford F-150
GMC Savana
GMC Sierra
GMC Yukon
Jeep Commander
Jeep Grand Cherokee
Lincoln Town Car
Mercedes Benz C230
Mercury Grand Marquis
Nissan Armada
Nissan Titan
Pontiac Montana
Saturn Relay

Cylinder Deactivation

Buick Rainier
Chevrolet Avalanche
Chevrolet Impala
Chevrolet Monte Carlo
Chevrolet Silverado
Chevrolet Suburban
Chevrolet Tahoe
Chevrolet Trailblazer
Chrysler 300
Chrysler Aspen
Dodge Charger
Dodge Durango
Dodge Magnum
GMC Envoy
GMC Sierra
GMC Yukon
Honda Odyssey
Honda Pilot
Jeep Commander
Pontiac Grand Prix

Variable Valve Lift and Timing

Chrysler 300C
Ford (many vehicles)
GMC Yukon
Honda (most vehicles)
Jeep Grand Cherokee
Infiniti G35
Lexus IS
Toyota (most vehicles)

Stoichiometric Direct Injection

Acura RDX
Audi A3, A4, A6, A8, RS, S6, S8
BMW 760Li
Chevrolet Express
Chevrolet Silverado
Dodge Ram
Ford Econoline
Ford F-Series
GMC Savana
GMC Sierra
Jeep Cherokee
Lexus GS, DI, IS
Mazda CX-7
Mazda Mazdaspeed
Mercedes E320
Pontiac Solstice
Saturn Ion
Saturn Sky
Volkswagen Eos
Volkswagen GTI
Volkswagen Jetta
Volkswagen Passat
Volkswagen Touareg

Turbocharging

Acura RDX
Audi A3, A4
BMW 330
Chevrolet Express
Chevrolet Silverado
Chrysler PT Cruiser
Dodge Caliber
Dodge Ram
Ford Econoline
Ford F-Series (250, 350)
GMC Savana
GMC Sierra
Jeep Grand Cherokee
Mazda CX-7
Mazda Mazdaspeed
Mercedes E320
Mercedes ML320
Mercedes R350
Porsche 911
Saab 9-3 Series
Subaru Impreza
Subaru Legacy
Subaru Outback
Volkswagen Beetle
Volkswagen GTI
Volkswagen Jetta
Volkswagen Passat
Volvo 40, 50, 60, 70, R Series
Subaru Forester
Volkswagen Touareg
Volvo XC70

Automated Manual Transmission

Audi A3
BMW M-Series
Volkswagen Eos, GTI, Jetta

Six-Speed Transmission

Audi A3, A4, A6, A7, RS, S4, Q7
BMW 3-Series, 5-Series, 7-Series, M-Series, Z4-Series
BMW X5
Cadillac Escalade, SRX
Cadillac STS, XLR
Chevrolet Corvette
Chevrolet Silverado
Chrysler Sebring
Dodge Ram Pickup
Ford 500
Ford Edge
Ford Expedition
Ford Explorer
Ford Fusion
GMC Acadia
GMC Sierra
GMC Yukon
Jaguar S-Type, XJ-Series, XK-Series
Lexus GS, IS, LS460, SC430
Lincoln MKZ
Land Rover LR3, Range Rover
Lincoln Mark MKX
Lincoln Navigator
Mazda6, MX-5 Miata, RX8
Mazda CX-7, CX-9
Mercedes G-Class, GL-Class, M-Class, R-Class
Mercedes C-Class, CL, CLK, CLS, E-Class, S-Class, SL, SLK
Mercury Milan
Mercury Montego
Mercury Mountaineer
Mitsubishi Outlander
Saab 9-3 Series
Saturn Aura
Saturn Outlook
Toyota Camry
Volkswagen Beetle
Volkswagen Jetta
Volkswagen Passat
Volkswagen Touareg
Volvo 80 Series, R-Series
Volvo XC90

Electric Power Steering

Acura NSX
Fiat (most vehicles)