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THE POTENTIAL FOR ENERGY-EFFICIENT TECHNOLOGIES TO REDUCE CARBON EMISSIONS IN THE UNITED STATES: TRANSPORT SECTOR

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ABSTRACT

The world is searching for a meaningful answer to the likelihood that the continued build-up of greenhouse gases in the atmosphere will cause significant changes in the earth's climate. If there is to be a solution, technology must play a central role. This paper presents the results of an assessment of the potential for cost-effective technological changes to reduce greenhouse gas emissions from the U.S. transportation sector by the year 2010. Other papers in this session address the same topic for buildings and industry. U.S. transportation energy use stood at 24.4 quadrillion Btu (Quads) in 1996, up 2 percent over 1995 (U.S. DOE/EIA, 1997, table 2.5). Transportation sector carbon dioxide emissions amounted to 457.2 million metric tons of carbon (MmtC) in 1995, almost one third of total U.S. greenhouse gas emissions (U.S. DOE/EIA, 1996a, p. 12). Transport's energy use and CO_2 emissions are growing, apparently at accelerating rates as energy efficiency improvements appear to be slowing to a halt. Cost-effective and nearly cost-effective technologies have enormous potential to slow and even reverse the growth of transport's CO_2 emissions, but technological changes will take time and are not likely to occur without significant, new public policy initiatives. Absent new initiatives, we project that CO_2 emissions from transport are likely to grow to 616 MmtC by 2010, and 646 MmtC by 2015. An aggressive effort to develop and implement cost-effective technologies that are more efficient and fuels that are lower in carbon could reduce emissions by about 12% in 2010 and 18% in 2015, versus the business-as-usual projection. With substantial luck, leading to breakthroughs in key areas, reductions over the BAU case of 17% in 2010 and 25% in 2015, might be possible. In none of these case are CO_2 emissions reduced to 1990 levels by 2015.

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ABSTRACT

The world is searching for a meaningful answer to the likelihood that the continued build-up of greenhouse gases in the atmosphere will cause significant changes in the earth's climate. If there is to be a solution, technology must play a central role. This paper presents the results of an assessment of the potential for cost-effective technological changes to reduce greenhouse gas emissions from the U.S. transportation sector by the year 2010. Other papers in this session address the same topic for buildings and industry. U.S. transportation energy use stood at 24.4 quadrillion Btu (Quads) in 1996, up 2 percent over 1995 (U.S. DOE/EIA, 1997, table 2.5). Transportation sector carbon dioxide emissions amounted to 457.2 million metric tons of carbon (MmtC) in 1995, almost one third of total U.S. greenhouse gas emissions (U.S. DOE/EIA, 1996a, p. 12). Transport's energy use and CO_2 emissions are growing, apparently at accelerating rates as energy efficiency improvements appear to be slowing to a halt. Cost-effective and nearly cost-effective technologies have enormous potential to slow and even reverse the growth of transport's CO_2 emissions, but technological changes will take time and are not likely to occur without significant, new public policy initiatives. Absent new initiatives, we project that CO_2 emissions from transport are likely to grow to 616 MmtC by 2010, and 646 MmtC by 2015. An aggressive effort to develop and implement cost-effective technologies that are more efficient and fuels that are lower in carbon could reduce emissions by about 12% in 2010 and 18% in 2015, versus the business-as-usual projection. With substantial luck, leading to breakthroughs in key areas, reductions over the BAU case of 17% in 2010 and 25% in 2015, might be possible. In none of these case are CO_2 emissions reduced to 1990 levels by 2015.

PURPOSE

The goal of this analysis is to illustrate the reductions in carbon emissions from U.S. transport that could be achieved in the year 2010 by a plausible scenario of the development and use of approximately cost-effective technology. Cost-effectiveness is a fuzzy, rather than a precise criteria, as will be discussed below. It includes not only the costs and fuel savings to consumers, but also the orderly turnover of productive capital by vehicle manufacturers. No changes in taxes or prices of energy versus the base case are made. Carbon emission reductions result solely from technological improvements. No specific public policies are postulated, although it is virtually certain that new and aggressive policy measures would be required.

Carbon emissions causing global climate change is a nearly perfect example of a public good externality. It has long been established that private markets, lacking public policy intervention, will ignore the potential damages caused by environmental externalities, leading to excessive damage to the environment. Therefore, public policy initiatives will be essential to bringing about the technological change necessary to reduce carbon emissions from transport. In this report, we assume that the steps necessary to insure the development and adoption of cost-effective technologies are implemented. We do not attempt to specify what those policies might be, or which policies are the most effective.

A major conclusion of our analysis is that reducing transportation's CO_2 emissions by means of cost-effective technology will take time: on the order of decades. In a study focussed on 2010, there is a danger of mistaking the slowness of technological change with the eventual size of its impact. Thus, we add the year 2015 to our projections, but even 2015 is too soon to see the full impacts of the technologies included in our scenarios. It is our hope that this will help to inform policy-makers about the importance of timing, both to society's ability to reduce carbon emissions and to the cost of those reductions.

SCENARIO DEFINITIONS AND METHODOLOGY

Three scenarios were defined for this study, all based on the U.S. Department of Energy, Energy Information Administration's (EIA's) 1997 Annual Energy Outlook (AEO) Reference Case (U.S. DOE/EIA, 1996b). The Reference Case projection foresees nearly flat world oil prices through 2015. In 1995 dollars per barrel, the Reference Case projects the price of oil to increase from $17.26 in 1995 to $18.20 in 2000, $20.41 in 2010 and $20.98 in 2015. By comparison, the U.S. refiner cost of imported oil in 1996 averaged $20.66 in 1996 dollars (U.S. DOE/EIA, 1997, table 9.1). As a result, the prices of transportation fuels remain relatively constant. The price of gasoline, for example, rises from $1.15 per gallon in 1995 to $1.23 in 2010, but then falls to $1.18 per gallon in 2015 (1995$). Other transport fuel prices are similarly steady. Despite relatively constant fuel prices, transportation energy use increases at only 1.4% per year through 2015. This is due in part to relatively slow rates of growth in transportation demand (1.4% per year for cars and light trucks, 2.1% annually for freight trucks and 3.7% per annum for air travel), and in part to continued modest increases in energy efficiency (about 1% per year for the air and rail modes, half a percent per year for highway vehicles). Nonetheless, light duty vehicle fuel economy, as measured by Environmental Protection Agency tests, improves for passenger cars from 27.5 mpg in 1995 to 31.5 mpg in 2010 and 32.6 mpg in 2015. Light truck mpg rises from 20.5 in 1995 to 22.9 in 2010 and 24.2 in 2015. No increase in automotive fuel economy standards is assumed.

In the EIA Reference Case, total transportation energy use grows from 24.3 quads in 1995 to 31.1 quads in 2010 and 32.0 quads in 2015. Passenger cars and light trucks continue to account for the majority of transportation energy use, 17.26 quads in 2010, 17.43 in 2015. Air makes the biggest increase, from 3.18 quads in 1995 to 5.00 in 2015. Freight trucks are close behind, with energy use growing from 5.43 quads in 1995 to 7.70 in 2015. Transportation's carbon emissions also grow at the rate of 1.4% per year in the Reference Case, from 465.1 MmtC in 1995 to 597.7 in 2010 and 614.5 in 2015. Far from returning to 1990 levels, 2010 CO_2 emissions are up by almost 30%.

The Business-as-Usual (BAU) scenario makes one change to the EIA Reference Case: passenger car and light truck fuel economy numbers are held constant at 1997 levels of 27.5 mpg for cars and 20.5 mpg for light trucks. Our reasoning is that federal automotive fuel economy (CAFE) standards are now binding (i.e., hold fuel economy above what would prevail in an unregulated market). As evidence, we note that the average fuel economy of light duty vehicles (passenger cars plus light trucks) has not changed significantly since 1982, despite the adoption of new technologies (such as multipoint fuel injection and 4-valve per cylinder engines) that could have produced substantial fuel economy gains. Instead, all of the potential of these technologies has gone to enhancing other vehicle attributes, such as weight and horsepower. As long as the CAFE standards are a binding constraint on light-duty vehicle fuel economy, this should continue to be the case. However, if enough technological progress is made that the standards are no longer binding, then light-duty vehicle mpg could begin to increase as foreseen in the EIA's Reference Case. Which view is more correct is an appropriate subject for future research.

All of the remaining assumptions of the EIA's 1997 AEO Reference Case are maintained in the BAU Case. This includes a substantial increase in the market shares of alternative fuel vehicles. Primarily as a result of zero emission vehicle (ZEV) regulations in California, the Reference Case foresees annual sales of 75,000 battery-powered electric cars and 150,000 electric light trucks in 2010. In addition, sales of hybrid electric vehicles mount to 250,000, with the result that over 2 million battery-powered and hybrid electric vehicles are on the road in 2010. Sales of natural gas vehicles also increase to 325,000 units annually in 2010, with a total on-road stock of 2.6 million light-duty vehicles. This is more than thirty times the 82,000 CNG vehicles in use today. These significant increases in alternative fuel vehicle sales and usage are retained in all scenarios.

An additional scenario was created by assuming: (1) that technological progress would be more rapid than assumed in the EIA Reference Case, and (2) that policies necessary to insure the use of cost-effective fuel economy technology were implemented. For light-duty vehicles, cost-effectiveness was not determined by simply comparing the discounted present value of fuel savings with incremental cost. Rather, it was determined by the technology adoption algorithms of the National Energy Modeling System (NEMS) Transportation Sector Model (U.S. DOE/EIA, 1994). These algorithms recognize that: (1) not all consumers have the same discount rates or vehicle use rates, (2) there may be other, nonmonetary attributes of technologies that consumers or society will value, and (3) premature retirement of manufacturing capital equipment will increase costs and so cost-effective market penetration generally takes time. In the NEMS transportation model, while simple cost effectiveness is the key determinant of market acceptance, market share is determined by a dynamic simulation of actual market behavior that is sensitive to the degree of cost-effectiveness. Thus, technologies that are not quite cost-effective will generally attain some market share, and technologies that are barely cost-effective are more likely to attain just a bit more than 50% than 100% of the market. Thus, to the extent that the NEMS model correctly simulates the market's adoption of technology, all of the improvements in light-duty vehicle fuel economy in all scenarios should be considered cost-effective.

For heavy trucks and other transport modes, energy efficiency is determined by different means. Simulation procedures are used to determine the market shares of efficiency technologies for the commercial air and heavy trucks modes. A user-specified introduction date determines the earliest year in which an advanced technology can be used. Once the cost of fuel for the mode in question surpasses a user-specified "trigger price", the technology begins to penetrate the market according to a time-dependent market penetration curve that is also determined by user-specified parameters. For rail, marine and pipeline modes, rates of efficiency improvement are specified by the modeler. For none of these modes is an explicit cost-effectiveness calculation made.

The "Efficiency" scenario was created by making reasonable, incremental assumptions about how a concerted effort to accelerate the development and promote the adoption of low-CO_2 technologies could make advanced technologies available sooner, lower their cost and insure their use. Key assumptions for light-duty vehicles are, (1) that times to market introduction of advanced technologies already included in the 1997 AEO Reference Case (EEA, Inc., 1996) can be reduced by 25% by increased emphasis on technology

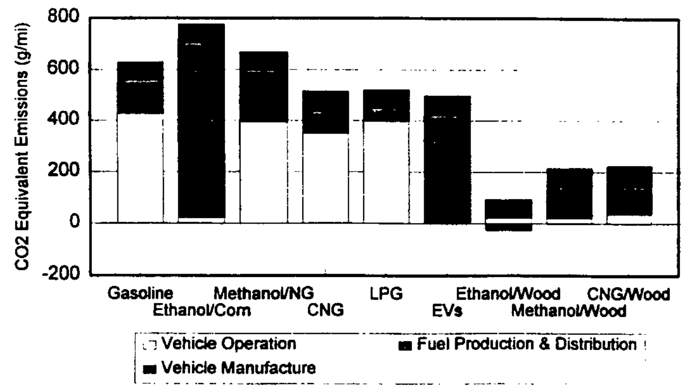
R&D, (2) that the new technologies shown in Table 1 will be added to the list, and (3) that costs for certain key technologies can be reduced by 30%. Development of a lean NO_X catalyst is the critical technological advance necessary to make the direct injection stratified charge (DISC) engine viable in the United States. The turbocharged direct injection (TDI) diesel engine requires this and reductions in particulate emissions, as well. Both types of hybrid vehicle will require advances in the efficiencies of electric motors, energy storage devices, controllers, and regenerative braking systems, as well as cost-reductions in all of these components. In the Efficiency scenario, neither the diesel hybrid nor the fuel cell hybrid is included, and the 2-stroke gasoline engine, which is on the Reference Case list, is also dropped in order to reduce the number of new powerplants manufacturers must introduce over a short period of time.

TABLE 1. NEW LIGHT-DUTY VEHICLE TECHNOLOGIES ADDED TO THE EFFICIENCY AND HIGH EFFICIENCY SCENARIOS

Technology	MPG Benefit (%)	Price Increase	Weight (lbs.)	Intro. Date
DISC	16	$300	50	2000
Turbo DI Diesel	40	$1100	125	2004
Hybrid/Gasoline	33	$3000	250	2005
Hybrid/Diesel	54	$3500	350	2005
Drag VI	11.5	$256	60	2012
Gasoline Fuel Cell Hybrid	84	$800	0	2007

Several advanced truck technologies were brought into the forecast by reducing the trigger price at which they become cost-effective. These include: (1) the LE-55 diesel engine (21% efficiency improvement over today's engines), (2) light-weight materials to reduce empty weight by 10%, (3) the turbo-compound diesel engine, and (4) advanced drag reduction (see, e.g., Greene, 1996). For commercial aircraft, an efficiency improvement of 40% was projected for new aircraft by 2015, comprised of 25% engine efficiency gains and 15% aerodynamic and light-weight materials (NRC, 1992). The efficiency of freight railroads was assumed to improve at 2% per year versus 1% per year in the Reference Case but still lower than the 2.8% rate achieved over the past 20 years.

Biomass fuels derived from wood and used as a blending component in conventional gasoline may be a cost-effective way to reduce carbon emissions. As a neat fuel, even advanced methods of producing ethanol from cellulose would be unable to compete with gasoline, given the low oil prices of the 1997 AEO Reference Case. Other alternative fuels, such as compressed natural gas (CNG) and battery-powered electric vehicles (EVs) generally produce about 20% less CO_2 on a fuel cycle basis (Figure 1), and could do even better in the future with significant technological advances. Yet because these technologies tend to cost more than conventional vehicles, and generally require compromising certain other attributes (e.g., range, refueling frequency), as well, they may not be cost-effective strategies for reducing carbon emissions. Furthermore, EVs and CNG vehicles already achieve significant market penetrations in all scenarios.



Source: Leiby, et al., 1996, table D-4.

FIGURE 1. FUEL CYCLE GREENHOUSE GAS EMISSIONS: LIGHT-DUTY VEHICLES

Cellulosic ethanol, on the other hand, offers more than a 90% net reduction in carbon emissions and recent studies indicate that it is likely to be cost-effective on its own merits as an oxygenate and octane-enhancer for conventional gasoline. Cellulosic ethanol supply curves developed by Bowman et al. (1997), and a refinery demand curve for ethanol as a gasoline blending agent developed by Hadder (1997) are shown in Figure 2. These curves indicate a market demand for cellulosic ethanol of about 5 billion gallons per year by 2010.

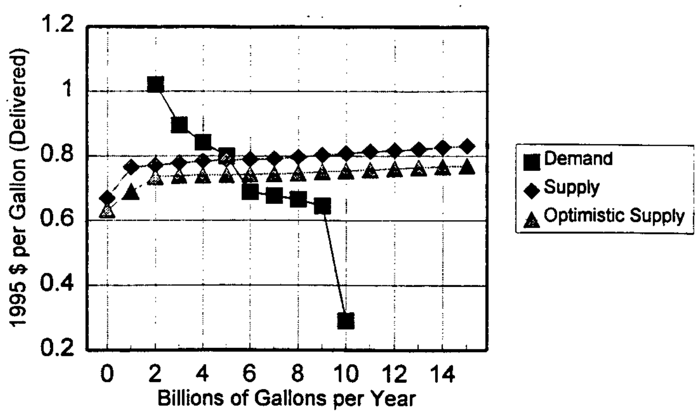


FIGURE 2. BIOMASS ETHANOL SUPPLY AND DEMAND FOR ETHANOL IN GASOLINE BLENDING IN 2010

The High-Efficiency scenario is distinguished from the Efficiency scenario in that it assumes breakthroughs in key technologies and combines them with generally greater success in developing and implementing low carbon technologies. Breakthroughs were assumed in areas likely to yield the greatest

CO_2 emission reductions but were not assumed in all areas that could produce significant reductions since this would drastically decrease the likelihood that such a scenario could occur. In the light-duty vehicle sector, a fuel cell hybrid vehicle using gasoline as a fuel was introduced in the year 2007. The gasoline-fuel cell vehicle is the configuration envisioned by the PNGV research program (NRC, 1997), and is intended as a transition technology to eventually lead to the more efficient and less-polluting hydrogen fuel cell vehicle. Given significant technological breakthroughs, the gasoline fuel cell vehicle could be more than 80% more efficient than today's gasoline internal combustion engine vehicles. In addition, the 2-stroke and diesel hybrid vehicles are reintroduced. Efficiency gains for the gasoline and diesel hybrids are also boosted to 42% and 72%, respectively, on the grounds that the same technologies needed to make the gasoline fuel cell vehicle successful will also improve these hybrids.

In the other modes, a diesel hybrid was introduced for medium-heavy trucks which typically operate in local pick-up and delivery mode. The truck diesel-hybrid was assumed to offer the same 72% benefit over conventional gasoline engines, and was introduced in 2005. Greater success in developing other technologies was simulated by shortening their times to 99% market share from 20 years to 15 years, for most technologies. In the air mode, efficient propfan engines were assumed to become marketable in 2005, but only for the smaller commercial jets (about one third of the fleet). Propfans offer a 10-15% improvement over even the ultra-high bypass turbine engines included in the Efficiency scenario. Additionally, partial success in producing a practical hybrid laminar flow control system is assumed to reduce the aerodynamic drag of new jets yielding a fuel economy benefit of 9%. The rate of efficiency improvement for rail is boosted to 2.5% per year reflecting the very gradual penetration of fuel cell technology in the locomotive market (reaching a 5% market share by 2010). The rate of efficiency improvement for waterborne freight is increased from 0.5% per year to 1% to reflect a 10 percent total efficiency gain achievable through improved hull designs and coatings.

All of these technology assumptions were entered into the NEMS Transportation Sector model input files and the model run to produce new forecasts. The assistance of the professional staff of the EIA is gratefully acknowledged. Of course, the responsibility for any errors made in the use of the model rests entirely with the authors and not the EIA.

Projected Impacts on Carbon Emissions and Energy Use

The Efficiency scenario indicates that cost-effective, advanced energy technologies could reduce emissions of CO_2 from the U.S. transportation sector by 12% in 2010 and 18% in 2015 versus the BAU case (Table 2). Three percentage points (or one fourth) of the 2010 reduction comes from the use of cellulosic ethanol as a blending agent for gasoline. Of the total 3 quad reduction in energy use in 2010, two thirds is achieved by light-duty vehicles, with nearly all the rest approximately evenly divided between freight trucks and commercial air.

In the High Efficiency scenario,CO_2 emissions are reduced by 17% in 2010 and 25% in 2015 versus the BAU case (Table 3). Cellulosic ethanol's contribution remains at 3%, however, because postulated reductions in the cost of cellulosic ethanol are offset by the contraction of the gasoline market due to greater vehicle fuel economy. Energy savings amount to 4.5 quads in 2010 and 7.3 quads in 2015. Once again, the vast majority of the energy savings come from the largest energy using mode, light-duty highway vehicles. Only in the High Efficiency scenario in 2015 are CO_2 emissions from transportation brought below 1997 levels.

Clearly, light-duty vehicle fuel economy is the key factor in reducing transportation's carbon emissions. In the Efficiency scenario, new passenger car fuel economy reaches 37.5 mpg in 2010 and 41.4 in 2015. Light truck mpg grows from 20.5 mpg in 1997 to 27.1 in 2010 and 31.9 in 2015. The fuel economy of the on-road fleet of vehicles lags considerably. By 2015, the on-road fleet fuel economy is still only 24.0 mpg. Part of this is due to a "slippage" of about 15% between EPA test and actual on road fuel economy. The rest is due to the time required to fully turn over the stock of motor vehicles. Eventually, the fleet on-road fuel economy would reach about 32 mpg. Even by 2015, only a little more than one third of the ultimate improvement in light-duty vehicle fleet fuel economy has actually occurred. In the High-Efficiency scenario, new passenger car fuel economy exceeds 40 mpg in 2010 and 50 mpg in 2015. New light truck mpg increases from 20.5 to 30.8 in 2010 and 37.8 in 2015. Still, the on-road fleet efficiency reaches only 23.2 in 2010 and 27.1 in 2015. The long lag between the efficiency of new equipment and the efficiency improvement of the total stock of vehicles is typical of all other transport modes as well. Indeed, lifetimes for aircraft, marine vessels and locomotives are typically two to three times that of light-duty highway vehicles.

SUMMARY AND CONCLUSIONS

Cost-effective technology can significantly reduce the transport sector's CO_2 emissions by 2010, but the greatest impacts will occur after that date. Reductions on the order of 10% appear to be possible by 2010 and by 2015 reductions of up to 25% might be achievable. However, changing the technology of transportation requires retooling the motor vehicle manufacturing industry and then turning over the vast stock of transportation vehicles. This requires decades. As a result, the impact of advanced technologies introduced between now and 2010 will only just begin to be felt in 2010 and will still not have achieved its full effect by 2015. The CO_2 reductions shown in Tables 2 and 3 represent perhaps one third to one half of the ultimate savings the technologies introduced in the two efficiency scenarios would ultimate realize. Thus, it does not appear to be possible, for example, to reduce the transport sector's carbon emissions below 1990 levels by 2010 by means of cost-effective technological solutions alone. To achieve reductions that large that fast will almost certainly require either demand reduction (e.g., through a carbon tax) or extensive use of technology that is less than cost effective at today's energy prices.

Even the cost-effective technological advances examined in this analysis won't necessarily happen without public policy intervention. First, because carbon emissions are a classic public good externality they are effectively ignored by private markets. Thus, there is no reason to expect the marketplace to invest in developing technologies that are particularly good at reducing CO_2 emissions. Second, while a simplistic model of markets would suggest that all cost-effective technologies will always be adopted

TABLE 2. TRANSPORTATION SECTOR ENERGY USE AND ENERGY EFFICIENCY PROJECTIONS TO 2010 AND 2015

	1997	2010				2015			
	BAU	BAU	Eff.	Diff.	%	BAU	Eff.	Diff.	%
Energy Use (Quads)	25.49	32.33	29.26	-3.07	-9%	33.96	28.72	-5.24	-15%
Carbon Emissions (MMT C/Yr.)	486.9	615.9	543.3	-72.6	-12%	646.0	531.8	-114.2	-18%
Fuel Use by Fuel Type (Quads)									
Motor Gasoline	15.08	18.02	15.23	-2.79	-15%	18.72	13.47	-5.25	-28%
Cellulosic Ethanol (in motor gasoline)	0.00	0.00	0.46	0.46	***	0.00	0.43	0.43	***
Distillate	4.56	5.78	5.65	-0.13	-2%	6.00	6.47	0.47	8%
Jet Fuel	3.55	4.67	4.16	-0.51	-11%	4.95	4.22	-0.73	-15%
Residual	1.17	1.64	1.64	0.00	0%	1.78	1.78	0.00	0%
Other	1.13	2.22	2.13	-0.09	-4%	2.51	2.35	-0.16	-6%
Energy Use by Mode (Quads)									
Light-Duty Vehicles	14.63	18.21	16.27	-1.94	-11%	19.07	15.50	-3.57	-19%
Freight Trucks	5.55	6.80	6.27	-0.53	-8%	7.07	6.25	-0.82	-12%
Air	3.59	4.71	4.20	-0.51	-11%	5.00	4.27	-0.73	-15%
Rail	0.48	0.51	0.43	-0.08	-16%	0.51	0.41	-0.10	-20%
Marine	1.74	2.30	2.30	0.00	0%	2.46	2.47	0.01	0%
Pipeline	0.75	0.88	0.88	0.00	0%	0.93	0.93	0.00	0%
Other	0.23	0.29	0.29	0.00	0%	0.30	0.30	0.00	0%
Energy Efficiency Indicators									
New Car MPG	27.5	27.8	37.5	9.70	35%	27.9	41.4	13.50	48%
New Light Truck MPG	20.5	20.6	27.1	6.50	32%	20.6	31.9	11.30	55%
Light-Duty Fleet MPG	19.6	19.4	21.5	2.10	11%	19.5	24.0	4.50	23%
Aircraft Efficiency (Seat-Miles/Gal.)	51.8	58.2	61.6	3.40	6%	60.6	66.1	5.50	9%
Freight Truck Fleet MPG	5.6	6.0	6.8	0.80	13%	6.1	7.4	1.30	21%
Rail Efficiency (ton-miles/1,000 Btu)	2.7	3.0	3.6	0.60	20%	3.2	3.9	0.70	22%

TABLE 3. TRANSPORTATION SECTOR ENERGY USE AND ENERGY EFFICIENCY PROJECTIONS TO 2010 AND 2015

	1997	2010				2015			
	BAU	BAU	High Eff. /Low Carbon	Diff.	%	BAU	High Eff. /Low Carbon	Diff.	%
Energy Use (Quads)	25.49	32.33	27.88	-4.45	-14%	33.96	26.67	-7.29	-21%
Carbon Emissions (MMT C/Yr.)	486.9	615.9	511.5	-104.4	-17%	646.0	484.4	-161.6	-25%
Fuel Use by Fuel Type (Quads)									
Motor Gasoline	15.08	18.02	13.87	-4.15	-23%	18.72	11.22	-7.50	-40%
Cellulosic Ethanol (in motor gasoline)	0.00	0.00	0.65	0.65	***	0.00	0.72	0.72	***
Distillate	4.56	5.78	5.65	-0.13	-2%	6.00	6.74	0.74	-12%
Jet Fuel	3.55	4.67	4.01	-0.66	-14%	4.95	4.00	-0.95	-19%
Residual	1.17	1.64	1.64	0.00	0%	1.78	1.77	-0.01	-1%
Other	1.13	2.22	2.05	-0.17	-8%	2.51	2.22	-0.29	-12%
Energy Use by Mode (Quads)									
Light-Duty Vehicles	14.63	18.21	15.21	-3.00	-16%	19.07	13.84	-5.23	-27%
Freight Trucks	5.55	6.80	6.17	-0.63	-9%	7.07	6.18	-0.89	-13%
Air	3.59	4.71	4.06	-0.65	-14%	5.00	4.06	-0.94	-19%
Rail	0.48	0.51	0.38	-0.13	-25%	0.51	0.31	-0.20	-38%
Marine	1.74	2.30	2.28	-0.02	-1%	2.46	2.43	-0.03	-1%
Pipeline	0.75	0.88	0.88	0.00	0%	0.93	0.93	0.00	0%
Other	0.23	0.29	0.29	0.00	0%	0.30	0.30	0.00	0%
Energy Efficiency Indicators									
New Car MPG	27.5	27.8	43.1	15.30	55%	27.9	50.2	22.30	80%
New Light Truck MPG	20.5	20.6	30.8	10.20	50%	20.6	37.8	17.20	83%
Light-Duty Fleet MPG	19.6	19.4	23.2	3.80	20%	19.5	27.1	7.60	39%
Aircraft Efficiency (Seat-Miles/Gal.)	51.8	58.2	64.6	6.40	11%	60.6	70.7	10.10	17%
Freight Truck Fleet MPG	5.6	6.0	7.0	1.00	17%	6.1	7.5	1.40	23%
Rail Efficiency (ton-miles/1,000 Btu)	2.7	3.0	4.0	1.03	34%	3.2	4.8	1.63	51%

Note: Because some light truck energy use is included in the freight truck sector, the totals by mode will not add to the totals by fuel type.

by all, in reality major technological changes involve risks (such as the risk of major vehicle redesign to achieve fuel savings that are of relatively modest value to consumers) that can slow the rate of adoption of innovations. Given the essentially flat fuel prices foreseen in the 1997 AEO Reference Case through 2015, it is difficult for us to imagine how most of the technological changes examined in this paper could occur without major new public policy initiatives.

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