Transportation on a Greenhouse Planet: A Least-Cost Transition Scenario for the United States

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SUMMARY

This paper presents the projected outcome of a transportation energy strategy through which the United States can achieve major reductions of carbon dioxide (CO_2) emissions by 2030. The results are based on an analysis of the U.S. economy that was performed to demonstrate the benefits of an economically and environmentally sound energy policy. An end-use based approach was applied to project transportation activity and energy demand associated with expected future growth in population and industrial output. Cost-effective levels of technological efficiency improvement and renewable fuels substitution were evaluated using a least environmental cost paradigm, in which externality costs are considered along with the direct investment and operating costs of the technologies. Adopting the technology and infrastructure changes foreseen in this scenario would require addressing many significant barriers and uncertainties. These are identified along with the major policy initiatives that would be needed to begin a transformation of the U.S. transportation system to one compatible with significant constraints on CO_2 emissions.

Projections for the environmental scenario highlighted in this paper are presented relative to a reference scenario which assumes no changes from present policies and trends. For year 2030, the environmental scenario achieves energy end-use reductions, relative to the reference case, of 73% for personal travel in light duty vehicles, 37% for freight modes, and 33% for domestic air travel. Overall, transportation sector energy use is cut 53%, from a reference projection of 28.6 Quads down to 13.4 Quads. Consistently across the subsectors, about three-fourths of the reduction is due to technology efficiency improvement and the remainder is from shifting to more efficient modes. Petroleum use, which is now nearly 100% of the 22 Quads used by the transportation sector, falls to 7 Quads by 2030 in the environmental scenario, versus 27 Quads in the reference case. These efficiency improvements, coupled with a moderate use of renewable fuels (3.2 Quads), reduce transportation sector CO_2 emissions by 62% relative to the reference case in 2030. This is a 50% absolute reduction from 1990 transportation CO_2 emissions of 1.9 billion tons per year. Emissions of other air pollutants are also greatly reduced, by 50% for nitrogen oxides and reactive hydrocarbons and by 30% for sulfur oxides and particulates, relative to the reference case in 2030.

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Chapter 11

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The results presented here are drawn from a collaborative study undertaken by energy conservation organizations to develop an end-use-based energy strategy for the United States (UCS et al. 1991). The project analyzed the potential for policy-driven pursuit of efficiency and renewable resources to significantly reduce the economic costs, environmental impacts, and petroleum dependency of energy use in the United States. Separate analyses were performed for transportation, residential, commercial, industrial, and electric-utility sectors; the transportation sector analyses were conducted by the authors of this chapter.[1] Sectoral results were integrated using the

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[1] Other members of the America's Energy Choices project contributed to the development and refinement of the transportation analysis, particularly Howard Geller, Jeff Hall, Dan Lashof, Alden Meyer, and Mary Beth Zimmermann. We are also most grateful to a number of individuals who provided information for the project and reviewed drafts of the report on which this chapter is based. The extensive comments and constructive criticisms provided were invaluable to us in developing this work. We also thank David Greene and Dan Santini, editors of these proceedings, and the reviewers, who provided many helpful comments on the conference draft.

LEAP energy and environmental accounting model.[2] The overall analysis and results of the study, including extensive supporting policy recommendations, are documented in the *America's Energy Choices* report (UCS et al. 1991). This chapter focuses on a selected scenario from that analysis and discusses the resulting projections of energy use and CO_2 emissions for the year 2030.

Four scenarios, termed the reference, market, environmental, and climate stabilization scenarios, were developed for the America's Energy Choices study. Projections were made for forty years out, to year 2030, with intermediate results for years 2000 and 2010. These scenarios are fully discussed in UCS et al. (1991).

The *reference scenario* reflects a continuation of current policies, practices, and trends. It is not a frozen efficiency projection and roughly corresponds to the EIA/SR (1990) reference projection; the key differences will be noted shortly.

The *market scenario* incorporates technologies for efficiency and renewable supplies that are estimated to be cost-effective to energy consumers without consideration of externalities. Public-policy changes would be needed to overcome some of the market failures and institutional barriers to the adoption of the technologies. Particularly in the near term, we hold the efficiency levels to what we judge might be achievable even though they may fall short of the estimated cost-effective levels. For example, technology penetration limitations restrict the year 2000 target for automobile fuel economy to 40 mpg even though our analysis indicates a cost-effective level of 43 mpg.

In the *environmental scenario*, some externalities are monetized by assuming fuel tax levels based on estimated costs of air pollution emissions and other societal costs (such as petroleum security costs). Greenhouse gas emissions costs—for example, as might be reflected with a carbon tax—are not included. The incorporation of externalities allows us to select even greater levels of efficiency and makes certain renewable supplies more competitive with conventional energy supplies. We consider our environmental scenario to approach a least-societal-cost reconfiguration of energy utilization in the United States in that major external costs are incorporated into decision making and in that cost-effectiveness is evaluated from a societal (rather than private) perspective. The environmental scenario is the particular focus of this chapter.

Finally, a *climate stabilization scenario* was developed. This scenario incorporates a carbon tax of $25/ton in addition to the externality

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[2] LEAP stands for "Long-range Energy Alternatives Planning," a computerized energy-planning system (Tellus 1990).

costs included in the environmental scenario. Additional efficiency improvements and fuel shifts are also assumed as needed to achieve absolute reductions of CO_2 emissions of 20% by 2000 and 50% by 2030, relative to the 1988 level. Not surprisingly, the shifts needed for the 2000 target appear nearly impossible to realize. Nevertheless, the climate stabilization scenario usefully indicates the changes needed to meet such specific near-term greenhouse gas emissions reduction goals.

Greenhouse gas emissions reduction targets would pertain to the U.S. economy as a whole, not to each individual sector. Nevertheless, it is instructive to examine the results for the transportation sector alone. Compared with 1990 CO_2 emissions of 1.9 Gt/yr (10^9 tons per year), 2030 CO_2 emissions are 50% lower in the environmental scenario. In the reference scenario, by comparison, CO_2 emissions grow by 32% over the forty-year horizon. The environmental scenario thus represents a cut of 62% of the 2.5 Gt/yr otherwise projected for 2030. As discussed below, these reductions are achieved largely through efficiency improvement, with help from mode shifting and fuel substitution. We believe that this case represents a projected outcome that would be societally cost-effective and achievable through aggressive policy measures and a significant shift of investments into efficiency and renewable resources. Although the environmental scenario reflects a net societal benefit, it is not necessarily a "no losers" scenario, since the requisite investment shifts would entail major changes in the allocation of economic resources.

Assumptions and Analyses

We took as our starting point the EIA (Energy Information Administration, U.S. Department of Energy) transportation sector model (EIA/TED 1990) and the National Energy Strategy service report (EIA/SR 1990). We then developed a reference case using the efficiency levels and fuel mix projections from the EIA work. Our reference case differs from EIA's in terms of the underlying activity levels that drive transportation demand. Our reference case technical efficiency and fuel mix assumptions are essentially the same as EIA's. The energy savings and CO_2 emissions reduction estimates made here are for our environmental scenario relative to the reference scenario.

For personal travel, we made our own projection of vehicle-miles of travel (VMT). Figure 11-1 shows historical and projected VMT for various scenarios (the policy scenario projections are discussed below). Our VMT projection is driven higher than EIA's in the mid-term by demographic data, but then drops lower as population stabi-

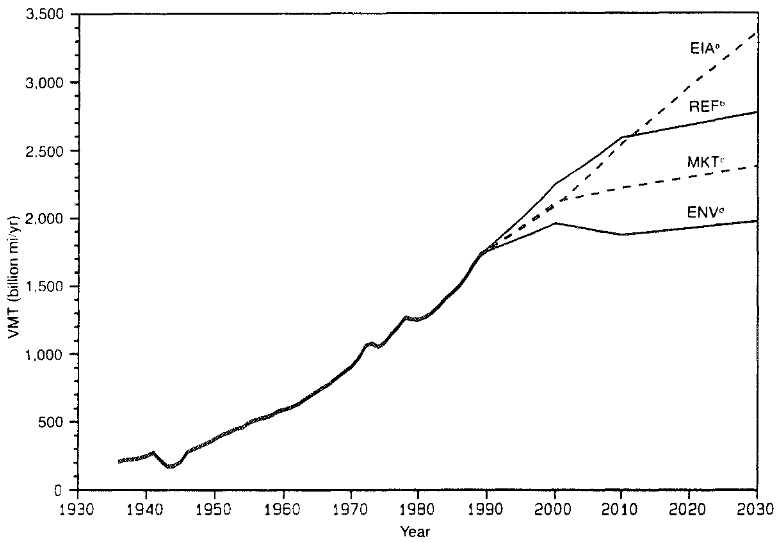

Figure 11-1. Past and Projected Light-Duty Vehicle Travel in the United States

Source: UCS et al. (1991), Figure C1.

Notes:

[a] EIA = EIA/SR (1990) reference scenario.
[b] REF = Reference scenario used in this analysis.
[c] MKT = Market scenario.
[d] ENV = Environmental scenario.

lizes and some assumed saturations in vehicle ownership and women's driving come into play.[3] Alone, this difference accounts for an 18% drop, or 2.9 quads in year 2030 light-duty vehicle energy demand in our reference case as compared with EIA's.

The demand for freight services is driven by the amount and types of industrial output. Our industrial sector is modeled differently from EIA's, generally reflecting trends toward lowered materials intensity and a shift toward services (UCS et al. 1991, 60–61; Williams, Larson & Ross 1987). To maintain the same level of overall economic activity

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[3] We use the projections of Spencer (1989) for population over age sixteen, adjusting for projected immigration and deducting the portion over age eighty-five, which cuts another 1% by 2030; see Appendix C of UCS et al. (1991) for further details.

(GNP) as projected by EIA, we assumed increased growth in the commercial-services sector, which does drive part of freight transportation demand. However, these shifts result in our reference case freight demand being 2.2 quads (23%) lower than EIA's in 2030.[4] Some truck-to-rail mode shifting is assumed in the environmental scenario, but the overall level of freight service demand (ton-miles) is the same as in the reference scenario.

For the environmental scenario, we based our projections of potential efficiency improvement on a combination of identified technologies plus extrapolations on rates of technical improvement. For the near term, which we identify as projection year 2000, our technology improvements are based on conservation supply curves developed for automobiles (Ross, Ledbetter & An 1991) and heavy trucks (Sachs et al. 1991). These two modes currently account for about two-thirds of transportation energy use, and their respective assessments list only measures for which estimated efficiency benefits and technology costs are known. Aircraft efficiency is based on the assessment of Greene (1990). Although cost-effectiveness was not identified for all of the measures, we assigned progressively higher identified efficiency levels to our more aggressive scenarios. The technology efficiency levels used for the environmental scenario highlighted in this chapter are intermediate levels, between those used for the market and climate stabilization scenarios presented in UCS et al. (1991).

Light-Duty Vehicles

In the reference case, the average rated fuel economy of new light-duty vehicles is assumed to improve 47% (new cars at 41 mpg) over the forty-year period through 2030 (Table 11-1). In contrast, a full implementation of presently existing measures cost-effective up to a fuel price of $1.47/gallon (1990$) could yield a 53% improvement (new cars at 43 mpg) over the next decade (Ross, Ledbetter & An 1991). A conservation supply curve showing the fuel economy improvement as a function of cost of conserved energy is shown in Figure 11-2, which also lists the cost/benefit assumptions for the technologies used. Average vehicle size and performance are based on the 1987 new-car fleet, and the technologies considered include only those that have been demonstrated to date. Table 11-1 shows the assumed fuel economies of new vehicles by scenario and year. For the environmental scenario, the

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[4] The comparison is for the comparably modeled domestic freight modes (truck, rail, domestic shipping), which EIA projects at 9.7 quads in 2030 (EIA/SR 1990, 202), versus our reference projection of 7.5 quads.

Table 11-1. Projected Fuel Economies of New Automobiles

	1988	2000	2010	2030
EPA test (55/45) mpg				
Reference[a]	28.6	33	37	41
Least private cost[b]		40	50	56
Least societal cost[c]		43	54	75
Climate stabilization[c]		46	59	75
On-road vs. test shortfall				
Reference[d]	20%	20%	25%	30%
Least private cost[e]		25%	200%	0%
Least societal cost[e]		20%	10%	0%
Climate stabilization[e]		20%	10%	0%
Annual rates of on-road improvement[f]				
Reference	4.1%[g]	1.1%	0.7%	0.5%
Least private cost		3.0%	2.9%	1.7%
Least societal cost		4.3%	3.7%	2.1%
Climate stabilization		5.3%	3.7%	1.8%

Notes:

[a] EIA/SR (1990), Table G-3.

[b] For 2000, authors' target, based on Ross, Ledbetter & An (1991); for 2010 and 2030, the medium-risk and high-risk estimates, respectively, given by EEA (1991) for 2010, adjusted downard to reflect elimination of shortfall.

[c] As in note *b*, with more ambitious schedule and assuming further technical improvements, optimization for on-road driving, and improvement of driving conditions (e.g., speed limit enforcement), so that shortfall is eliminated and the 75 mpg (EEA high-risk estimate for 2010) is achieved by 2030.

[d] EIA/SR (1990), Table 3-4, p. 85.

[e] Authors' targets, as discussed in notes *b* and *c*.

[f] For new vehicles, from previous year to projection year, as calculated from the test mpg and shortfall assumptions.

[g] New automobiles, 1977–1988, from Heavenrich, Murrell & Hellman (1991), Table 1, and assuming a 15% shortfall in 1977.

corresponding evolution of the fuel economy of the entire vehicle stock is given in Table 11-2.

Most of the technologies assumed for the environmental scenario are already in use, although many of the engine and load reduction technologies have been applied to enhance power performance rather than to improve fuel economy in recent years. Idle-off, or engine start-stop, has been used in some European cars, but its market has been limited. A significant fraction of driving time is spent in idle. Idle-off

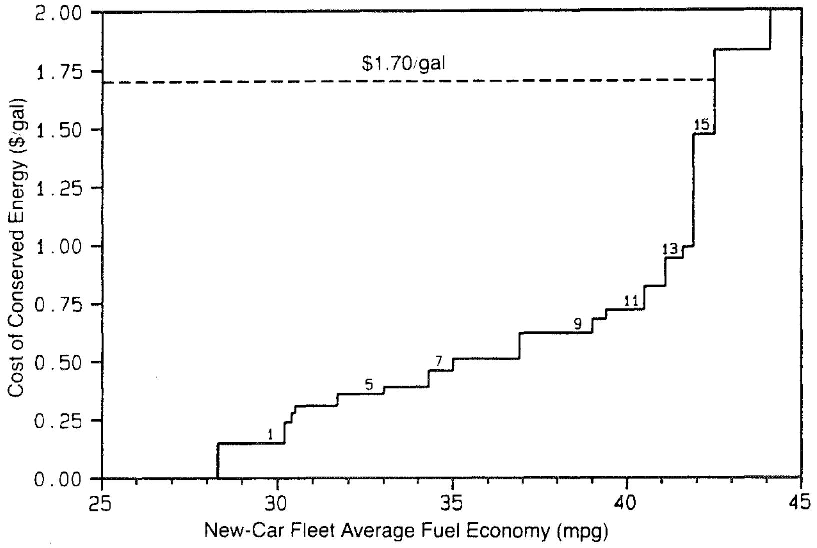

Figure 11-2. Cost of Fuel Economy Improvement for Automobiles

COST/BENEFIT ASSUMPTIONS

Technology	Indiv. New-Car Mpg Increase (%)	Retail Price Increase ($)	Market Share Increase (%)	Avg. Cum. Consumer Cost ($)	Fleet EPA Mpg	Cost of Conserved Energy ($/gal)	Cum. Avg. CCE ($/gal)
Baseline: 1987 new fleet					28.3		
Transmission management	9.0	60	75	45	30.2	0.15	0.15
Roller cam followers	1.5	15	37	51	30.4	0.24	0.15
Torque converter lockup	3.0	35	16	56	30.5	0.28	0.16
Overhead cam	6.0	74	69	107	31.7	0.31	0.21
Advanced friction reduction	6.0	80	80	171	33.0	0.36	0.25
Intake valve control	6.0	80	75	231	34.3	0.39	0.27
Front-wheel drive	10.0	150	23	266	35.0	0.46	0.29
4 valves/cylinder	6.8	105	100	371	36.9	0.51	0.33
Idle-off	15.0	250	50	496	39.0	0.62	0.37
Accessory improvements	1.7	29	80	519	39.4	0.68	0.38
Aerodynamic improvement	4.6	80	85	587	40.5	0.72	0.40
Multipoint fuel injection	3.5	67	56	624	41.1	0.82	0.42
Continuous variable transmission	4.7	100	45	669	41.6	0.94	0.43
Lube & tire improvements	1.0	22	100	691	41.9	0.99	0.44
5-speed auto overdrive transmission	4.7	150	40	751	42.5	1.47	0.47
Weight reduction	6.6	250	85	964	44.1	1.83	0.56
Advanced tires	0.5	20	100	984	44.2	2.01	0.57

Source: UCS et al. (1991), Table C8, based on Ross, Ledbetter & An (1991), assuming a 3% discount rate and 10-year term.

Table 11-2. Summary of Light-Vehicles Analysis, Environmental Scenario

	1990	2000	2010	2030
VMT, base (billion mi)	1,762	2,250	2,610	2,820
Land use/TDM effect	0.0%	-13.0%	-30.0%	-34.0%
Cost of driving effect	0.0%	0.5%	2.2%	4.4%
Net light vehicle VMT	1,762	1,969	1,884	1,986
Light truck fraction	0.29	0.31	0.32	0.32
Gasoline price (1990$/gal)	1.09	1.32	1.59	1.94
Avg. driving cost (cents/mi)	5.8	5.4	4.3	3.1
New-vehicle fuel economy (EPA mpg)				
Automobiles	28	43	54	75
Light trucks	21	32	41	56
Average new light vehicle	25	39	49	68
On-road fuel economy (mpg)				
Shortfall, on-road vs. EPA	20%	20%	10%	0%
New light-vehicle average	20.2	30.8	44.3	67.8
Stock fuel economy (on-road mpg)				
Automobiles	21	27	41	69
Light trucks	15	20	31	52
Stock average on-road	19	25	37	62
Average energy use (kBtu/mi)	6.65	5.10	3.34	2.01
Average annual improvement rate				
New light-duty vehicles		4.3%	3.7%	2.1%
Light-duty vehicle stock		2.7%	4.3%	2.6%
Relative efficiency by fuel type				
Petroleum	1	1	1	1
Natural gas	1.0	1.0	1.0	1.0
Biofuels	1.0	1.0	1.0	1.0
Hydrogen	1.0	0.9	0.9	2.5
Electric (end-use from grid)	2.5	2.3	2.3	2.5

Table 11-2. (continued)

	1990	2000	2010	2030
Shares of VMT by fuel type				
Petroleum	100.00%	97.67%	68.22%	5.83%
Natural gas	0.00%	0.40%	0.96%	0.08%
Biofuels	0.00%	1.92%	24.43%	66.38%
Hydrogen	0.00%	0.00%	0.00%	0.00%
Electric (end-use from grid)	0.00%	0.01%	6.39%	27.71%
End-use consumption (quads)				
Petroleum	11.715	9.812	4.296	0.233
Natural gas	0.000	0.040	0.060	0.003
Biofuels	0.000	0.193	1.539	2.650
Hydrogen	0.000	0.000	0.000	0.000
Electric (end-use from grid)	0.000	0.001	0.175	0.442
LIGHT-VEHICLE TOTAL (QUADS)	11.7	10.0	6.1	3.3

Source: UCS et al. (1991), Table C16.

is not particularly costly to implement, and its fuel savings are among the largest of any available technology (see Figure 11-2). Current market conditions offer no incentive to introduce such a technology (similar concerns have been raised for transmission management, also noted in Figure 11-2). However, idle-off is an example of a measure that would become viable with stronger efficiency standards, feebates, and other policies to encourage the direction of technological advances toward improving fuel economy. We assume that reaching these levels of vehicle efficiency will require such policy changes, including, at minimum, strengthened Corporate Average Fuel Economy (CAFE) standards. The environmental scenario also assumes a gasoline tax of $0.50/gallon, which begins to cover some of the societal costs of automobile use.[5] The resulting gasoline price in 2000 would be $1.70/gallon, which implies the cost-effectiveness of all but the last two measures in Figure 11-2.

By 2030, we assume new cars would reach a fuel economy of 75

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[5] Overall societal costs of automobile use were recently estimated to be $0.15–$0.30 per vehicle-mile of travel, or $3.00–$6.00 per gallon of gasoline for the current fleet average of 20 mpg (Moffet 1991).

mpg. This value matches the "risk level 3" estimate of EEA (1991) for the year 2010, which we are applying as a target for twenty years later than the EEA assessment. New cars rated at 75 mpg are also well within the range of existing prototype vehicles (see, for example, Bleviss 1988, Table 3-2). Achieving this level of improvement includes further refinement of existing technologies, identified in Figure 11-2, as well as new technologies now in active development, such as two-stroke engines, regenerative braking, electric and electric-hybrid drive trains, advanced batteries, fuel cells, and advanced materials substitution. Not all technologies would be used in all vehicles, of course, since some of these technologies address the same sources of inefficiency, particularly losses at part load. Advanced emissions control technologies, such as heated catalysts, heat batteries, and NO_x reduction catalysts may also come into play—the latter, for example, through its facilitation of lean-combustion-engine designs (which include lean-burn four-stroke and two-stroke spark-ignition engines and direct-injection diesel engines). Cost information is not available for technologies beyond those already fully demonstrated. For 2010 and later, therefore, we are assuming that applications of the identified technologies will be cost-effective compared with the assumed gasoline price of $2.10/gallon (1990$, including externalities taxes).

Table 11-1 lists the vehicle fuel economy assumptions for our various scenarios, and Figure 11-3 shows the resulting new-vehicle energy intensities, with past history shown for comparison. In the environmental scenario discussed here, there is a two-thirds reduction in light-vehicle energy intensity by 2030, corresponding to an average improvement rate of 3.1%/yr for new vehicles and 3.0%/yr for the entire stock. Assertive public policies will be required to effect such a transformation of the U.S. personal transportation fleet. The likely efficacy of ongoing increases in CAFE standards is analyzed by DeCicco (1992). Besides stronger standards, other helpful policies include market incentives (feebates), an increased gasoline tax, advanced vehicle competition and demonstration programs, strategic procurement of efficient vehicles by governmental and other fleets, and steady research and development support for advanced vehicle technologies. A degree of vehicle mix shifting may also be appropriate, which could ease the burden on technology improvement. From a CO_2 reduction perspective, obvious improvements in the mix would be a reversal of the popularity of inefficient light trucks (which are now one-third of new-vehicle sales) and an increase in specialized smaller vehicles, such as "sporty" but efficient two-passenger cars and commuter cars.

We acknowledge that automotive fuel economy improvements as

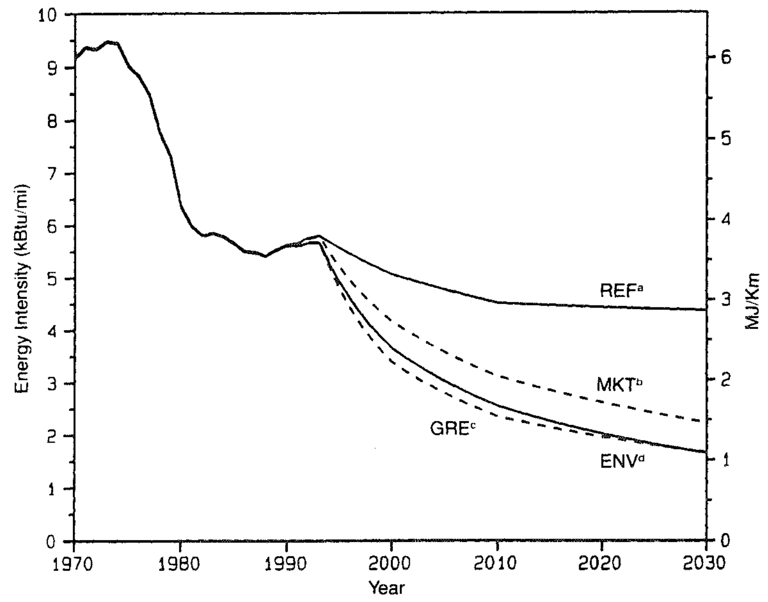

Figure 11-3. Past and Projected Energy Intensity of New Automobiles

Source: From UCS et al. (1991), Figure C2. Historical data from Heavenrich, Murrell & Hellman (1991) and USEPA (1980); projections based on new-vehicle rated fuel economy and shortfall assumptions shown here in Table 11-1.

Notes:

[a] REF = Reference scenario (same as EIA/SR 1990).

[b] MKT = Market scenario.

[c] GRE = Climate stabilization scenario.

[d] ENV = Environmental scenario.

significant as those in our environmental scenario are controversial. We do not acknowledge that there are significant technical or economic barriers to such improvement; rather, the barriers are mainly political and informational. This is an area in which a transition to vehicles having lower environmental impact may not be a "no losers" policy shift. Certainly, the resulting curtailment of gasoline demand would affect the petroleum industry. Ongoing significant fuel economy improvement would place burdens on the automotive industry that could constrain profitability but which are unlikely, of themselves, to affect employment. Historically, there is no evidence that cost-effective improvements in fuel economy have adversely impacted employment in the automotive industry, and future increases in fuel economy will not involve in any fundamental way a shift of production overseas. Rather, comprehensive studies, such as Womack, Jones & Roos (1990), indicate that the poor competitive position of some U.S. domestic automakers is the result of not keeping up with advances in production efficiency and management practice. On the other hand, measures taken to significantly decrease VMT (as discussed below) may dampen demand for motor vehicles.

A summary of the light-vehicle analysis is given in Table 11-2. We did not do an independent analysis of vehicle fuel types, but rather based our projected allocations and relative vehicle efficiencies by fuel type on the very high-conservation case of EIA/SR (1990). Since our scenario pushes efficiency farther, there should be no constraints on fuel availability. We lump alcohol-fueled vehicles (both combustion and fuel cell) together under the category "biofuels," which is projected to contribute two-thirds of the light-duty-vehicle supply by 2030. The next-largest category is electric vehicles. A hydrogen category is listed as a placeholder, since hydrogen utilized in a fuel cell is a promising possibility that could displace some of the other fuels over the forty-year horizon; biomass-derived methanol could also be used in fuel cell vehicles (DeLuchi, Larson & Williams 1991).

Personal Travel Demand

The reference scenario represents a continuation of the now-dominant patterns of urban and suburban growth. These involve heavy automobile dependence, as reflected in low densities, segregated uses, and subsidized road building. In contrast, the environmental scenario assumes a combination of policy changes to achieve denser urban development patterns, to institute transportation demand management, and to directly impose on users the full costs of their automobile use.

We assume a phase-in of mixed-use infill development strategies, so that after 2000, 75% of new population growth settles as urban infill and the remaining 25% is suburban infill, essentially halting sprawl onto vacant land. The resulting densification serves to greatly decrease VMT per person in the affected regions. Auto trips are shorter and at higher average occupancy, and there are shifts to walking, transit, and bicycling, as we presume development policies will also better facilitate these modes. We estimate that phase-in of densification can shave 5% from VMT growth by 2000 and 21% by 2030. This projection of VMT reduction is based on a number of studies that document a relationship between higher residential density, reduced automobile VMT, and increased transit usage (Newman & Kenworthy 1989; Pushkarev,

Table 11-3. Projected Impacts of Transportation Demand Management (TDM) in the Environmental Scenario

Measure	VMT Reduction
Commercial area parking charge of $0.01/min	4.6%
Subsidized transit and ride sharing	2.1%
Subsidized off-peak transit	1.5%
Employee parking charge of $3/day	1.2%
Regional congestion pricing to achieve only slightly congested roads (level of service C)	1.1%
Mileage- and smog-based registration fee (average $125/vehicle)	0.2%
$1.50/gal gasoline price adder, incorporating $0.50/gal tax (externalities other than greenhouse emissions) plus $1.00/gal for pay-at-the-pump insurance	6.1%
TOTAL[a]	16.5%

Source: From UCS et al. (1991), Table C3, derived from Harvey (1990).
Note:
[a] The total is less than the sum of the separate VMT reduction effects of the individual measures because of overlapping impacts on travel decisions, as indicated by the regional transportation modeling analysis on which the results were based.

Zupan & Cumella 1982).[6] For example, studies in the San Francisco, New York, and Chicago areas show that VMT declines 30% each time density doubles, if neighborhood commercial business is allowed (Holtzclaw 1990). Further documenting and quantifying these relationships and delineating the differences between and across metropolitan areas is a priority for further research.[7]

Transportation demand management (TDM) measures complement the densification to achieve further reductions in VMT. The measures listed in Table 11-3, based on the analyses of Harvey (1990), would themselves yield a 16.5% reduction of VMT. In combination with densification, the TDM measures add a net 13% reduction by 2030. Overall, the result is a 34% reduction of VMT compared with our reference case in 2030. This holds net growth in VMT to just 6% above the 1990 level, as shown by the lower curve in Figure 11-1. The

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[6] See also other studies reviewed in Newman & Kenworthy (1989) and in Holtzclaw (1990).

[7] Some of the uncertainties and issues involved as well as research needs are discussed by Deakin (1990) and Burwell, Bartholomew & Gordon (1990).

VMT reductions account for about one-third of the reduction in light-vehicle energy use; the rest comes from improved fuel economy.

The densification and TDM effects induce increases in urban transit usage. In the reference case, transit passenger-miles of travel (PMT) is flat over the forty-year horizon. The environmental scenario projects a fivefold increase in PMT by 2030 (average PMT growth rate of 4.3%/yr) based on a relation indicating that transit PMT grows by one-sixth the shrinkage in VMT (Holtzclaw 1990), relative to the reference case.

Regarding the investment needed for transit, on the basis of statistics reported in Gordon (1991) we estimate that there is no added cost (capital and operating) beyond what would have been needed for roads (construction and maintenance) displaced by shifting demand from personal vehicles to transit. For example, with the funding allocation flexibilities established in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), nearly one-half of highway program capital authorizations can be more broadly spent, including use for transit capitalization (see, for example, STPP 1992). This broadened funding ability will help to ensure that there are ample resources available to implement the infrastructure developments needed in our environmental scenario. It will also be essential to develop the planning capabilities and political will, at all levels of government, needed to successfully redirect the resources into a more efficient multimodal transportation system. Efforts to improve air quality, such as those required by the Clean Air Act Amendments of 1990, will be helpful in this regard. It should be noted that personal vehicle travel is not shifted exclusively to transit, since much of it goes to higher vehicle occupancy, walking and biking, or reduced travel distance.

This level of VMT reduction assumes the adoption of regulations and financial incentives that would achieve densification with compact, mixed-use infill development, particularly in transit corridors. These policies would be designed to discourage sprawl and encourage infill development in cities, towns, and surrounding suburbs. Relevant policies include zoning regulations, urban growth boundaries, greenbelt preservation, environmental regulations, incentives for dense and mixed-use development, and an enhanced integration of transportation and land use planning. Transportation demand management will also play a crucial role. Some TDM measures reduce direct transportation costs by providing better transit alternatives. Other measures increase the direct costs of driving (for example, via parking pricing and other user fees) to induce mode substitution, thereby reducing the externalities (air pollution, resource depletion, congestion costs) associated with driving. As noted above, a shift in public expenditures is also needed to expand transit capacity, moving revenues away from highways. In the environmental scenario, few or no new highways would be needed after 1995, since new development is shifted into areas where roadway infrastructure is already in place. A proportionately greater share of highway funding would be directed toward maintenance as well as toward making roadway infrastructure more conducive to use of efficient modes through enhancements such as high-occupancy-vehicle (HOV) lanes, good access to transit nodes, and making improvements to facilitate pedestrians and bicyclists.

A shift away from nearly exclusive automobile reliance and toward the alternative transportation and densification strategies contemplated in our environmental scenario will be controversial and will face considerable political hurdles. However, the other option of continuing down the current path of largely uncontrolled sprawl faces its own significant obstacles. Moreover, there are ancillary benefits, such as the potential for a revitalization of decaying urban centers, which can help to generate support for pursuing the environmentally motivated scenario outlined here. Public education on the economic, societal, and environmental benefits of such a shift in development will be essential to facilitate the transition and to build the political support needed to implement these policies.

Freight

Our freight transportation analysis starts with a set of freight service demand levels, in ton-miles per year by industrial subsector, from the 1985 recalibration of the Argonne National Laboratory (ANL) FRATE model (Vyas 1990). These statistics are used instead of the EIA activity-by-mode values (for example, truck VMT, rail ton-miles) to permit estimates of mode-shifting potential. The service demand levels for the eleven industrial subsectors were projected using the growth rates of our industrial sector model (UCS et al. 1991). We do not incorporate macroeconomic effects (for example, energy price changes) of different scenarios into the freight analysis; neither do we feed back the results of our industrial-sector analysis. Therefore, the results reflect only the effects of efficiency and mode changes within the freight transportation sector alone. The 1990–2030 freight mode efficiency improvements developed for the environmental scenario are shown in Table 11-4. A summary of the freight demand, energy intensity, and fuel mix assumptions along with the resulting end-use energy requirements is given in Table 11-5.

Regarding the technical potential for improving freight energy efficiency, a cost-benefit analysis was available only for near-term

Table 11-4. Freight Energy Efficiency Improvements in the Environmental Scenario, 1990–2030

ASSUMPTIONS REGARDING TRUCK-TO-RAIL MODE SHIFT POTENTIAL[a]			
Commodity Group	**Shipping in 1985 (10^9 ton-mi)**	**Current Truck Share**	**Portion That Cannot Shift to Rail**
Chemicals, rubber, plastics	286	41%	80%
Primary metals	113	68%	80%
Food	358	73%	80%
Paper	98	50%	100%
Refinery	488	18%	100%
Stone, clay, glass	158	79%	100%
Metal durable	189	80%	80%
Other manufacturing	216	75%	80%
Agricultural	453	67%	100%
Mining, including oil wells	1,296	3%	100%
Construction	151	100%	80%
Retail trade	140	100%	90%

TECHNICAL EFFICIENCY IMPROVEMENTS BY MODE[b]	
Mode	**1990–2030 Improvement of Ton-Mi/Btu**
Truck	101%
Rail	63%
Waterborne (domestic)	25%
Pipeline	25%
Air cargo	168%
AVERAGE FREIGHT SECTOR EFFICIENCY IMPROVEMENT	
Weighted by ton-miles and including mode shift effect	75%

Notes:

[a] Based on UCS et al. (1991), Table D3. Activity and mode share data are from the ANL FRATE model (Vyas 1990). Mode shift limitation assumptions are our own.

[b] Based on UCS et al. (1991), Table D10, with truck efficiency equivalent to heavy trucks reaching 10.5 mpg (see Figure 11-4) and air cargo efficiency equivalent to passenger aircraft at 100 SM/gal (see Table 11-7).

Table 11-5. Freight Transportation Analysis Summary, Environmental Scenario

	1990	2000	2010	2030
Activity (10^9 ton-miles)				
Truck	1,755	1,952	2,192	2,613
Rail	830	939	1,069	1,350
Water	851	863	888	898
Air	7.8	9.5	11.7	16.5
Pipeline	846	862	888	901
TOTAL	4,288	4,626	5,049	5,778
Truck loading (tons/vehicle)	5.59	5.59	5.59	5.59
Truck VMT (10^9)	314	349	392	467
Truck mpg	8.6	10.6	13.0	17.3
Energy intensity index				
Truck	1	0.815	0.664	0.498
Rail	1	0.895	0.796	0.612
Water	1	0.950	0.900	0.800
Air	1	0.793	0.512	0.373
Pipeline	1	0.950	0.900	0.800
Energy intensity (Btu/ton-mile)				
Truck	2,808	2,288	1,864	1,397
Rail	443	396	353	271
Water	402	382	362	322
Air	18,809	14,916	9,630	7,016
Pipeline	271	257	244	217
Energy by mode (quads)				
Truck	4.927	4.465	4.086	3.650
Rail	0.368	0.372	0.377	0.366
Water	0.342	0.330	0.321	0.289
Air	0.146	0.142	0.113	0.116
Pipeline	0.229	0.222	0.217	0.195
Other (not modeled) (quads)				
Natural gas pipelines	0.535	0.537	0.544	0.527
International shipping	0.717	0.851	0.984	1.047

Table 11-5. (continued)

	1990	2000	2010	2030
Energy by fuel (quads)				
Petroleum	6.490	5.931	5.204	3.572
Natural gas	0.535	0.729	1.006	1.913
Electricity (end-use)	0.239	0.232	0.226	0.205
Renewables	0.000	0.027	0.204	0.500
TOTAL ENERGY USE (QUADS)	7.263	6.918	6.642	66.190

Source: UCS et al. (1991), Table D10.

heavy-truck technologies. Trucking is, of course, the most important freight mode from an energy perspective. Air freight is more energy intensive, but it includes a smaller and more specialized fraction of all shipping, much of which is carried as belly cargo on passenger aircraft. Air freight is assumed to have the same efficiency improvement as passenger air (discussed below). For other modes, the efficiency improvement projections from the EIA/SR (1990) very high-conservation case are used.

Our estimates of the potential improvements in freight truck fuel economy are based on Sachs et al. (1991). The estimated conservation potential for heavy-truck efficiency technologies is shown in Figure 11-4, which plots the estimated cost of improvement against achievable fleet fuel economy relative to a baseline fleet at 5.2 mpg. Including engine technologies now in development, the estimated cost-effective heavy-truck fuel economy is 8.7 mpg. We also assume that lower road speed, corresponding to an enforced 55-mph speed limit, is desirable in the environmental case. Highway speed is not limited because it is cost-effective for an individual driver; particularly for freight trucking, the private cost might be high, as shown in Figure 11-4. Rather, speed limits are imposed for broader societal reasons (safety, environmental protection, decreased dependence on oil imports). Speed reduction brings the heavy-truck fuel economy potential up to 9.1 mpg, a 75% improvement over the baseline. Finally, since this assessment is based on near-term technologies, for the environmental scenario we extrapolate to a year 2030 potential of 10.5 mpg, or roughly a doubling (100% improvement) of the baseline.

Since the Sachs et al. (1991) analysis covered only "heavy-heavy" (within class 8) trucks, we assumed that a similar level of improvement could be achieved by freight trucks on average. The heaviest trucks

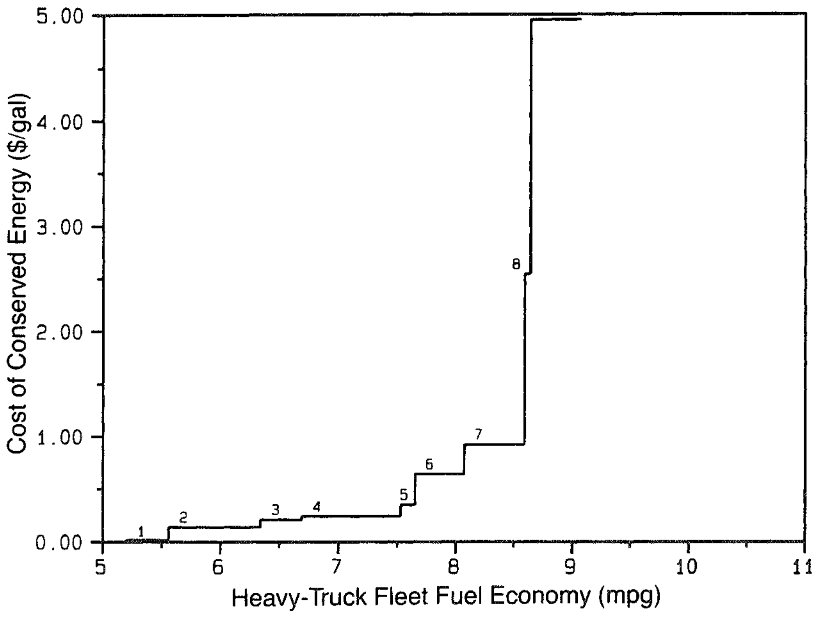

Figure 11-4. Cost of Fuel Economy Improvement for Heavy Trucks, 1990–2030

Technology	Cost ($)	Lifetime (mi)	MPG Benefit	Penetration	Fleet Mpg	CCE ($/gal)
Drive train	1	750,000	7%	100%	5.6	0.00
Other available engine technology	1,500	500,000	15%	100%	6.3	0.14
Aerodynamics—tractor	3,000	750,000	14%	48%	6.7	0.21
Engine control technologies	4,000	750,000	16%	100%	7.5	0.24
Aerodynamics—trailer	2,000	750,000	5%	48%	7.7	0.35
Tires	700	80,000	8%	100%	8.1	0.64
Engines in development[a]	10,000	750,000	10%	100%	8.6	0.92
Weight reduction	3,000	750,000	1%	100%	8.7	2.54
Speed reduction[b]	15,000	200,000	15%	55%	9.1	4.95

Source: Sachs et al. (1991), Figure 1, which can be referenced for further details.
Note: Assumes a baseline fuel economy of 5.2 mpg and a 3% discount rate.
[a] Includes turbocompounding, bottoming cycles, low-heat-rejection diesels.
[b] Not a technology, but rather the cost of longer driving times.

dominate the freight activity in terms of VMT. The light and medium classes of freight trucks are bracketed by passenger vehicles and heavy trucks, and as noted earlier, even higher levels of improvement are projected for light-duty vehicles. Therefore, we are comfortable with this assumption even though a specific assessment for all classes for freight trucks was not performed. We scaled the average freight truck fuel economy by the improvement in heavy-truck fuel economy using the ratio of the 8.6 mpg EIA/SR (1990) baseline for all freight trucks to the 5.2 mpg Sachs et al. (1991) baseline for heavy trucks. The resulting fuel economy and energy intensity projections are given in Table 11-5.

The present modal breakdown of intercity freight (ton-miles) is rail, 37%; trucks, 26%; oil pipelines, 21%; domestic water shipping, 16%; and air, 0.35% (Smith 1990). At present, a small fraction of purely domestic freight moves in intermodal service (containers or trailers on flatcars or dedicated vehicles, and "carless" trailers). There are many barriers to increasing intermodal shipping, of which the most important is that intermodal service takes longer for hauls less than about 500–600 miles, whereas, based on statistics in Smith (1990), average shipment distances are 252 miles (truckload) and 548 miles (less than truckload). Intermodal shipping has, however, doubled in the past decade and has good continued-growth potential in selected markets (Roberts & Fauth 1988). This may seem to run counter to the trend toward greater time-value of shipments; however, it is not conventional bulk-commodity rail service that we see growing. Rather, it is expanded competitiveness of intermodal services, which take advantage of inherent efficiencies of rail and the congestion avoidance possible with the use of an exclusive, fully scheduled right-of-way. Rail shipping uses about one-fourth as much energy per ton-mile as trucks do. Increasing the intermodal share will save energy if the rail system is near enough to origins and destinations. If not, the postulated savings are lost in drayage—that is, extra truck shipping to and from the rail terminals.[8]

Using an analysis of intermodal potential by commodity subsector, summarized in Table 11-4(a), we estimated that a maximum of 12% of intercity truck ton-miles could move to rail by 2030. In the environmental scenario, this shift is phased in starting with a 3.3% shift by the year 2000 and is reflected in the activity (ton-mile) projec-

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[8] Because rail routes are more circuitous than truck routes, one should add approximately 10% to the ton-miles shifted. Such an adjustment would increase rail ton-miles by about 3%, which, using our projected activity levels, would imply an additional 0.01 quad; this was neglected in our analysis.

Table 11-6. Freight Transportation Results, Reference Versus Environmental Scenarios

ENERGY END-USE		
	Quads	Change Relative to 1990
1990	7.3	—
Reference scenario 2030	9.8	+35%
Environmental scenario 2030	6.2	-15%
FUELS MIX, ENVIRONMENTAL SCENARIO FOR 2030		
Fuel	**Quads**	**Share**
Petroleum	3.6	58%
Natural gas	1.9	31%
Biofuels (renewable)	0.5	8%
Electricity (52% renewable)	0.2	3%

Source: UCS et al. (1991), 93, and Appendix E, 16–17.

tions given in Table 11-5. No shifts occur in the other modes. In particular, we did not consider the potential impact of new services that may become important over a forty-year horizon, such as shipment via highly automated and integrated transportation networks, high-speed rail, and displacement by electronic media.

Freight energy demands by mode were partitioned into renewable and nonrenewable fuels; we did not analyze splits within these categories (for example, alcohol versus biodiesel). Although we assumed moderate increases in natural gas as a land freight fuel, its contribution could be significantly higher, particularly for meeting near-term CO_2 emissions constraints. Natural gas is widely available, relatively low-cost, and burns rather cleanly. Compressed or liquefied natural gas may be suitable for fleet vehicles, heavy trucks, and rail (where liquefied natural gas might be carried in tenders behind the locomotive). For the freight sector environmental scenario, we did not attempt to specify the form of renewable fuel use, which could be alcohol or hydrogen in combustion engines or fuel cells.

As summarized in Table 11-6, the year 2030 environmental scenario projection for freight transportation energy end-use is 37% lower than the reference case projection. The reduction is achieved mainly through efficiency improvements, with a 1.2%/yr average rate of technology efficiency improvement between 1990 and 2030. Accounting for the truck-to-rail mode shift, there is 1.4%/yr average improvement rate in ton-miles moved per Btu. In the reference case, by comparison, there is essentially no average improvement, since the relatively small technology efficiency gains in all modes are offset by the projected higher activity growth rates of the more intensive modes, truck and air.

Although energy requirements and CO_2 emissions by the freight subsector can fall in absolute terms, the potential drop is not nearly so dramatic as that for light vehicles. Presently, light vehicles are the dominant transportation energy use, and they are projected to remain so in the reference case. In the environmental scenario, however, freight becomes the dominant user of transportation energy by 2030. The absolute fall in energy consumption from present levels is 15%, so there is a greater burden on fuel switching in the freight subsector if we seek a 50% cut in CO_2 emissions by 2030.

Although technology cost projections have large uncertainties, we estimate that these energy use reductions would be cost-effective in every scenario. With changes in land use patterns and urban transportation policies there could be additional savings, but we did not analyze the impact of these factors for freight transportation as we did so for personal travel. Changes that could impact freight energy needs include the following: Production could be located closer on average to consumption (although this would run counter to recent trends toward a more global economy). Land use and traffic policies could be implemented to facilitate freight movement; such policies could include HOV rush-hour lanes that convert to freight-only at night, and other congestion-limiting measures as discussed under personal transportation policies.

Intercity Passenger Travel

Reference case projections of personal air travel through 2010 were obtained from EIA/TED (1990). Activity levels and fuel efficiency were extrapolated to 2030 in a way consistent with pre-2010 trends and the EIA/SR (1990) results. Table 11-7 summarizes our intercity travel analysis. Overall intercity travel demand, as measured by passenger-miles of travel (PMT), is expected to more than triple by 2030, growing at average rates of 3.5%/yr between 1988 and 2010 and 2.5%/yr between 2010 and 2030. With reference case efficiency assumptions and no mode shifting, the resulting energy use would grow from the present level of about 2.9 quads to 5.4 quads by 2030.

Significant improvements in aircraft efficiency are possible, especially over the long run as the stock is replaced (Greene 1990). Presently, passenger-aircraft fuel economy averages 39 seat-miles per

Table 11-7. Intercity Air and High-Speed Rail, Summary of Analysis (All Scenarios)

Scenario and Year	1988	2000	2010	2030
Reference				
Air PMT (10^9)	513	762	1,082	1,772
Air SM/gal	39	52	62	73
Air energy intensity index	1.000	0.765	0.629	0.534
Air energy use (quads)	2.91	3.31	3.86	5.37
Market				
Air PMT (10^9)	513	762	1,017	1,577
HSR PMT (10^9)	0	0	65	195
Air SM/gal	39	51	62	73
Air energy intensity index	1.000	0.765	0.629	0.534
HSR energy intensity index	1.000	1.000	0.904	0.740
Air energy use (quads)	2.91	3.31	3.63	4.78
HSR energy use (quads)	0.00	0.00	0.09	0.21
TOTAL: AIR+HSR (QUADS)	2.91	3.31	3.72	4.99
Environmental				
Air PMT (10^9)	513	762	984	1,479
HSR PMT (10^9)	0	0	98	293
Air SM/gal	39	51	73	100
Air energy intensity index	1.000	0.765	0.534	0.390
HSR energy intensity index	1.000	1.000	0.904	0.740
Air energy use (quads)	2.91	3.31	2.98	3.27
HSR energy use (quads)	0.00	0.00	0.13	0.32
TOTAL: AIR+HSR (QUADS)	2.91	3.31	3.11	3.59

Source: UCS et al. (1991), Table C11.

Note: High-speed rail (HSR) efficiency improvements are assumed to be 1%/yr for all scenarios, starting from the year 2000 base of 0.9 kBtu/seat-mile (SM).

Table 11-7. (continued)

Scenario and Year	1988	2000	2010	2030
Climate stabilization				
Air PMT (10^9)	513	762	952	1,382
HSR PMT (10^9)	0	0	130	390
Air SM/gal	39	51	79	150
Air energy intensity index	1.000	0.765	0.9494	0.260
HSR energy intensity index	1.000	1.000	0.904	0.740
Air energy use (quads)	2.91	3.31	2.67	2.04
HSR energy use (quads)	0.00	0.00	0.17	0.43
TOTAL: AIR+HSR (QUADS)	2.91	3.31	2.84	2.46

Parameters

Jet fuel energy content: 135 kBtu/gal

Base air energy intensity: 3.462 kBtu/SM (fully loaded)

Base HSR energy intensity: 0.900 kBtu/SM (fully loaded)

Load factor (both air and HSR): 0.61

gallon (SM/gallon). The reference scenario projects improvement to stock average performance of 73 SM/gallon by 2030. In the environmental scenario, we assume this level of improvement by 2010 and a further improvement to 100 SM/gallon by 2030. This is within the levels estimated by Greene (1990), who identified aircraft technologies that could eventually push fleet efficiencies into the 110–150 SM/gallon range. The result is a 27% reduction in air energy use by 2030. We did not specifically analyze fuel substitution possibilities and thus assume continued use of petroleum fuels and their CO_2 emissions rates for aircraft.

Because of the large growth in air travel, the resulting airport congestion, and anticipated limits in new airport construction, several regions of the country are considering high-speed trains for intercity passenger service. The options include various forms of fast steel-wheel trains, such as the French *train de grande vitesse* (TGV), as well as magnetic levitation (Maglev) vehicles. We do not attempt to distinguish these in our analysis but classify them together as high-speed rail (HSR). HSR options are considered to be competitive (on both energy cost and travel time) at distances of generally 600 miles or less, which are estimated to account for about one-third of current domestic air PMT. By air, these shorter trips are more energy-intensive than longer flights. In the environmental scenario, we assume a phase-in of HSR, so that one-half of the shorter trips are shifted from air to HSR by 2030. We assume that HSR options will use 900 Btu/SM[9] in 2000 and improve at 1%/yr thereafter. HSR energy use then grows to 0.32 quads by 2030, contributing a net 8% reduction of intercity travel energy use compared with the reference case. Counting the aircraft efficiency improvements, the environmental scenario projection of energy use for intercity travel in 2030 is 3.6 quads, which is 33% lower than the reference projection.

Findings and Inferences

Table 11-8 summarizes the energy end-use results for our transportation sector analyses. All scenarios are shown, with a breakdown into light vehicles, freight, intercity passenger travel, and urban transit. For the environmental scenario on which this presentation focuses, we project a reduction in transportation energy use to 39% below the present level, in contrast to a 30% increase in the reference case. The largest reduction in the environmental scenario is by personal light vehicles, for which end-use drops from 11.7 quads in 1990 to 3.3 quads in 2030, versus rising to 13.3 in the reference case. Driving-age population is projected to grow at 0.6%/yr over the forty-year horizon; energy end-use shrinks at an average rate of 3%/yr in the environmental scenario, versus growth of 0.3%/yr in the reference case.

It is instructive to break down the reductions in energy use into components of technology improvement and mode shift. This is shown for the environmental scenario in Table 11-9. Consistently for all subsectors, it turns out that improved technology efficiency is responsible for three-fourths of the reduction, with shifts to more efficient mode accounting for the remainder. This is significant because the majority of the technology improvements have already been identified at present even though the projection is for forty years out. Widespread commercialization of the efficient transportation technologies involves some uncertainty, and costs are not fully identified. Nevertheless, there is still room for technological innovation, the further potential gains from which are not reflected in the scenarios. The mode shift portion rests on assumptions about policy changes to profoundly affect land use patterns and transportation infrastructure. As noted earlier, the personal travel mode shift projections are largely grounded in comparative data for areas that have developed according to different patterns; however, there is a lack of data on areas that have made a transition through time

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[9] A midrange value of rail and Maglev estimates obtained from D. Rote (1991).

Table 11-8. Transportation Energy End-Use Summary (All Scenarios)

Scenario (By End-Use Activity)	PROJECTED ENERGY END-USE (quads) 1990	2000	2010	2030
Reference				
Light vehicles	11.70	13.30	13.80	13.30
Freight	7.26	7.90	8.66	9.81
Intercity passenger	2.91	3.31	3.86	5.37
Urban transit[a]	0.15	0.15	0.15	0.15
TOTAL	22.0	24.7	26.5	28.6
Market				
Light vehicles	11.70	11.40	8.50	5.40
Freight	7.26	7.20	7.30	7.05
Intercity passenger	2.91	3.31	3.72	4.99
Urban transit[a]	0.15	0.19	0.26	0.23
TOTAL	22.0	22.1	19.8	17.7
Environmental				
Light vehicles[b]	11.70	10.00	6.10	3.30
Freight[b]	7.26	6.92	6.64	6.19
Intercity passenger[b]	2.91	3.31	3.11	3.59
Urban transit[a]	0.15	0.25	0.40	0.33
TOTAL	22.0	20.5	16.3	13.4
Climate stabilization				
Light vehicles	11.70	9.60	5.50	3.30
Freight	7.26	6.72	6.61	5.88
Intercity passenger	2.91	3.31	2.84	2.46
Urban transit[a]	0.15	0.34	0.40	0.33
TOTAL	22.0	20.0	15.4	12.0

Source: UCS et al. (1991), Table C13.

Notes:

[a] Urban transit results are from UCS et al. (1991), Table C5, assuming an average transit efficiency improvement rate of 1.3%/yr. This is based on a 50%–50% share split between bus and rail transit, and energy intensity (Btu/VMT) decreasing by 43% for buses and by 39% for rail (EIA/SR 1990, 218). We did not do a specific conservation assessment for bus efficiency. Rather, we assumed that buses have an efficiency improvement potential similar to that of freight trucks. Some heavy-truck measures (such as engine, tire, and lubrication improvements) are directly applicable; others (such as aerodynamics) are less so; however, other significant options (such as regenerative braking) not assumed for heavy trucks are applicable to buses.

[b] For the environmental scenario, light-vehicle results are from Table 11-2, freight results are from Table 11-5, and intercity passenger results are from Table 11-7.

Table 11-9. Breakdown of Transportation Sector Energy Use Reductions in 2030, Environmental Scenario Versus Reference Scenario

	ENERGY USE (quads) Reference Scenario	QUADS OF REDUCTION (% reduction) Efficiency	QUADS OF REDUCTION (% reduction) Mode Shift	ENERGY USE (quads) Environmental Scenario
Personal travel (nonintercity)	13.45	7.50 (77%)	2.29 (23%)	3.66
Freight	9.81	2.73 (76%)	0.87 (24%)	6.19
Intercity travel	5.37	1.35 (76%)	0.43 (24%)	3.59
TOTAL	28.63	11.59 (76%)	3.60 (24%)	13.44

Source: UCS et al. (1991), Table C12.

Note: The breakdown for each subsector was obtained by factoring the ratio of environmental (*ENV*) to reference (*REF*) scenario energy use (E), into an efficiency portion (p), and a mode shift portion (q), according to $E_{ENV}/E_{REF}=(1-p)(1-q)$. The absolute energy reduction, $E_{ENV}-E_{REF}$, was then broken into two components proportional to p and q. The percent contributions of technology improvement and mode shift to the reduction are thus taken to be $p/(p+q)$ and $q/(p+q)$, respectively.

from highway-mode intensive transportation to denser development and a multimodal transportation system.

These results show that although there is a larger burden on technology improvement in achieving energy use reductions consistent with a greenhouse-constrained economy, technology cannot be expected to achieve the needed energy use reductions alone. Significant policy changes are needed to push both technology improvement and shifts to more efficient modes. The three-to-one ratio suggested here is not fully certain, of course, and technological advances could reduce the burden on mode shifting. This breakdown was not, however, foreordained, since the analyses were done independently under similar guidelines about likely cost-effectiveness, externality costs, and policy change.

Besides reducing energy consumption through efficient technologies and shifts to less intensive modes, the other important way to cut CO_2 emissions is to switch to renewable fuels. With the steep energy use reductions indicated here, there is a smaller burden on fuel switching, which increases the possibility that the CO_2-renewable fuel supply system can be sustainable in the broader sense of having minimal disruptions to natural ecosystems. Petroleum use now accounts for essen-

Table 11-10. Transportation Sector Energy Use and CO_2 Emissions in 2030, Environmental Scenario Versus Reference Scenario

	Energy End-Use (quads)	CO_2 Emissions (10^9 tons/yr)	CO_2 Factor (10^6 tons/quad)
Base year estimates for 1990	22.0	1.90	86
Reference scenario in 2030	28.6	2.50	87
(change from 1990)	(+30%)	(+32%)	(+1%)
Environmental scenario in 2030	13.4	0.95	71
(change from 1990)	(−39%)	(−50%)	(−17%)

tially 100% of the 22 quads, or 11 Mbd (million barrels per day), used by the transportation sector. By 2030, it drops to 7 quads (54% of end-use) in the environmental scenario versus 27 quads (94% of end-use) in the reference case. Further reductions in petroleum use and its attendant CO_2 emissions could be obtained from greater use of biofuels or renewably generated hydrogen. For example, DeLuchi, Larson & Williams (1991) suggest that hydrogen- or methanol-powered fuel cell vehicles may offer significant environmental benefits and be economically competitive with petroleum-powered vehicles on a life-cycle-cost basis. Presently, however, it is premature to pick winners or losers among the various renewable fuel options. Our results are therefore based on use of a generic biofuel, which is assumed to supply 3.2 quads (23%) of transportation energy end-use by 2030 in the environmental scenario.

Table 11-10 shows the environmental scenario results for transportation sector CO_2 emissions in 2030, assuming no net CO_2 emissions from biofuels. The 50% absolute reduction in CO_2 emissions is obtained in part by fuels substitution, mainly in the light-vehicles subsector, so that CO_2 emissions per unit of energy consumption are reduced by 17%. As noted regarding the energy use reduction breakdown in Table 11-9, the 15-quad cut in transportation energy end-use is achieved largely through efficiency improvement, which is responsible for 76% of the reduction. Mode shifting accounts for the remainder. In addition to a halving of CO_2 emissions, other air pollution from the transportation sector is also significantly reduced. We assume that the more stringent of the emissions levels specified in the 1990 Clean Air Act Amendments (for example, Tier II tailpipe standards) are completely phased in by 2030 in all scenarios (see UCS et al. 1991, Appendix I). Since we did not differentiate scenarios by emissions standards for criteria pollutants, differences in emissions projections between scenarios depend only on reduced levels of VMT and overall transportation sector fuel use. The environmental scenario projects emissions reductions relative to the reference scenario of 50% for nitrogen oxides and reactive hydrocarbons (NO_x and RHC) and 30% for sulfur oxides and particulates (SO_x and TSP) by 2030.

Issues for Further Analysis

The large reductions in transportation sector energy use and CO_2 emissions projected for the environmental scenario will clearly require significant changes in transportation and energy policy. The technical and economic feasibility of the technology improvements invoked in the analysis has the firmest underpinning among the assumptions used. Published information on efficient technologies was used for the major energy-intensive transportation modes—light-duty vehicles, heavy trucks, and passenger aircraft. Indeed, the assumptions are technologically conservative since neither new innovations nor technology breakthroughs are assumed over the forty-year horizon of the study. Extrapolations regarding similarity in improvement rates were assumed for some of the other modes, and these estimates should be refined with further analysis.

The potential for significant mode-shifting adopted in our environmental scenario is based on cross-sectional analyses of Holtzclaw (1990) and extrapolations of the regional TDM assessments of Harvey (1990). These results are more controversial because they go beyond the possibilities suggested by conventional transportation planning models used in the United States. Nevertheless, comparisons with areas having much lower levels of highway mode activity than are presently typical in the United States provide evidence that automobile dependency is not necessary for healthy economic development. Although such results are provocative, what is less clear is the process by which such a transition can be made. Needed are better time series data on land use characteristics for areas that have undergone different development patterns, resulting in significantly different per capita VMT.

The alternative-fuels aspects of the analysis also need further development. In particular, there is scope for greater use of natural gas, particularly as a transitional fuel in earlier years. As noted earlier, we did not include any hydrogen use in the environmental scenario, although by 2030 this may be a promising fuel in electric vehicles powered by fuel cells.

There are a number of economic issues raised by the analysis as well. The meaning of least societal cost in the context of transportation planning needs to be better refined. Our definition is based on the few energy-related environmental externalities for which societal costs estimates are available, primarily regulated air pollutants, plus petroleum security costs. Other societal costs are also involved, which could affect the outcome of the analysis in either a positive or negative way. Our technology cost information is also limited, with the most complete information being available for near-term technologies. Further analysis is needed to refine the estimates of longer-run cost-effectiveness; this will be an ongoing effort in the transportation and energy policy.

The environmental least-cost paradigm behind our analysis implies that the environmental scenario is in some sense a "no regrets" scenario, since the changes are estimated to be cost-effective to society, if not always to private individuals. It is not necessarily a "no losers" scenario, since there are dislocations involved that would place different burdens on and yield different benefits to various groups of consumers and industries. In particular, the petroleum and other fossil fuel industries would be under pressure to either diversify into the provision of less environmentally damaging energy services or face significant losses of income. Such potential economic changes certainly bear further examination, since political feasibility may hinge on a sharing of benefits with parties who would otherwise have a vested interest in business-as-usual. Further economic issues yet to be addressed include macroeconomic effects, energy price feedbacks, equity, and fiscal changes involved in the imposition of environmental taxes, such as those considered in the environmental scenario.

Conclusion

Under the assumptions of our environmental scenario, significant reductions in petroleum use, overall energy use, and carbon dioxide emissions are projected by the year 2030. The technology changes, mode shifts, and fuel substitutions utilized in making the projections are estimated to be cost-effective when considering environmental externality costs along with the direct investment and operating costs of transportation technologies.

Relative to a reference projection that assumes no changes from present policies and trends, the environmental scenario achieves energy end-use reductions of 73% for personal travel in light-duty vehicles, 37% for freight modes, and 33% for domestic air travel by the year 2030. Overall, transportation sector energy use is cut 53%, from the reference projection of 28.6 quads down to 13.4 quads in 2030. Consistently across the subsectors, about three-fourths of the reduction is due to technology efficiency improvement, and the remainder is from shifting to more efficient modes. Petroleum use, which is now nearly 100% of the 22 quads (11 Mbd) used by the transportation sector, falls to 7 quads (3.6 Mbd) in the 2030 environmental projection, versus 27 quads (14 Mbd) in the reference case. These significant energy use reductions, coupled with a moderate use of renewable fuels (3.2 quads), yield a 50% absolute reduction in CO_2 emissions from the U.S. transportation sector, which are presently 1.9 billion tons per year. Further emissions reductions would be possible with a greater shift to renewable fuels, such as hydrogen, which were not fully analyzed in the present study.

Major changes in transportation and energy policy would be required to achieve the benefits identified in the environmental scenario. The requisite policy assumptions were briefly mentioned here and are fully discussed in the longer report on which this paper is based (UCS et al. 1991). Our projection of the significant reductions of CO_2 emissions that could be achieved following our environmental scenario does involve considerable uncertainties. However, our examination of the options for improving efficiency and using renewable resources suggests that the greater source of uncertainty has to do with political and institutional barriers rather than technology or cost hurdles. Clearly, significant new investments will be required to follow a strategy such as that outlined in our environmental scenario. However, our results indicate that following such a path will be less costly to the United States than a continuation down the present transportation path of increasing reliance on inefficiently used fossil fuels. The CO_2 emissions reductions projected for the environmental scenario are all achieved at net economic benefit according to the factors considered here. This is what we mean in characterizing our environmental scenario as a "least-cost transition scenario." The results provided here offer a positive vision of the environmental and economic benefits of a transportation system more compatible with a greenhouse-constrained world. Presenting such a vision is an important step toward building the public support needed to change transportation policies in a way that will move the United States toward an environmentally sustainable economic system.

References

Bleviss, D. 1988. *The New Oil Crisis and Fuel Economy Technologies: Preparing the Light Transportation Industry for the 1990s.* New York: Quorum Press.

Burwell, D. G., K. Bartholomew, and D. Gordon. 1990. "Energy and Environmental Research Needs." In *Transportation, Urban Form, and the Environment.* Special Report 231. Washington, D.C.: Transportation Research Board.

Deakin, E. A. 1990. "Jobs, Housing, and Transportation: Theory and Evidence on Interactions Between Land Use and Transportation." In *Transportation, Urban Form, and the Environment.* Special Report 231. Washington, D.C.: Transportation Research Board.

DeCicco, J. M. 1992. *Savings from CAFE: Projections of the Future Oil Savings from Light Vehicle Fuel Economy Standards.* Washington, D.C.: American Council for an Energy-Efficient Economy. May.

DeLuchi, M. A., E. D. Larson, and R. H. Williams. 1991. *Hydrogen and Methanol: Production from Biomass and Use in Fuel Cell and Internal Combustion Engine Vehicles: A Preliminary Assessment.* Report No. 263. Princeton, N.J.: Center for Energy and Environmental Studies, Princeton University. August.

EEA. 1991. *An Assessment of Potential Passenger Car Fuel Economy Objectives for 2010.* Report prepared for the U.S. Environmental Protection Agency by Energy and Environmental Analysis, Inc. Arlington, Va. July.

EIA/SR. 1990. *Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy.* Service Report SR/NES/90-02. Washington, D.C.: Energy Information Administration. December.

EIA/TED. 1990. *Transportation Energy Demand Module for the PC-AEO Spreadsheet Model.* Washington, D.C.: Energy Information Administration.

Gordon, D. 1991. *Steering a New Course: Transportation, Energy, and the Environment.* Cambridge, Mass.: Union of Concerned Scientists.

Greene, D. L. 1990. *Energy Efficiency Improvement Potential of Commercial Aircraft to 2010.* Report ORNL-6622. Oak Ridge, Tenn.: Center for Transportation Analysis, Oak Ridge National Laboratory. June.

Harvey, G. 1990. *Draft Transportation Control for State Clean Air Plan* (June) and *Final Transportation Control Measure Plan* (November), prepared for the Metropolitan Transportation Commission, Oakland, Calif.

Heavenrich, R. M., J. D. Murrell, and K. Hellman. 1991. *Light-Duty Automotive Technology and Fuel Economy Trends Through 1991.* Ann Arbor, Mich.: U.S. Environmental Protection Agency. June.

Holtzclaw, J. 1990. *Explaining Urban Density and Transit Impacts on Auto Use*. San Francisco: Sierra Club. April.

Moffet, J. 1991. "The Price of Mobility." Draft Report. San Francisco: Natural Resources Defense Council. November.

Newman, P. W. G., and J. R. Kenworthy. 1989. *Cities and Automobile Dependence: A Sourcebook*. Aldershot, England: Gower Technical.

Pushkarev, B. S., J. M. Zupan, and R. S. Cumella. 1982. *Urban Rail in America: An Exploration of Criteria for Fixed Guideway Transit*. Bloomington: Indiana University Press.

Roberts, P. O., and G. R. Fauth. 1988. "The Outlook for Commercial Freight." In *A Look Ahead: Year 2020*. Special Report 220. Washington, D.C.: Transportation Research Board, National Research Council.

Ross, M., M. Ledbetter, and F. An. 1991. *Options for Reducing Oil Use by Light Vehicles: An Analysis of Technologies and Policy*. Washington, D.C.: American Council for an Energy-Efficient Economy. June.

Rote, D., Argonne National Laboratory, Argonne, Ill. 1991. Personal communication. April.

Sachs, H. M., J. M. DeCicco, M. Ledbetter, and U. Mengelberg. 1991. *Fuel Economy Improvement for Heavy Trucks: A View of Existing Technology, Future Possibilities, and the Potential Improvement*. Washington, D.C.: American Council for an Energy-Efficient Economy. August.

Smith, F. 1990. *Transportation in America*. 8th ed. Waldorf, Md.: Eno Foundation for Transportation.

Spencer, G. 1989. *Projections of the Population of the United States, by Age, Sex, and Race: 1988 to 2080*. Current Population Reports, Series P-25, No. 1018. Washington, D.C.: Bureau of the Census. January.

STPP. 1992. *Special issue: Transit and the New Legislation*. Bulletin #12. Washington, D.C.: Surface Transportation Policy Project. January 14.

Tellus (Tellus Institute and Stockholm Environment Institute). 1990. *LEAP (Long-range Energy Alternatives Planning): A Computerized Energy Planning System*. Vol. 1. *Overview*. Boston: Tellus Institute. January.

UCS et al. (Alliance to Save Energy, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, and Union of Concerned Scientists). 1991. *America's Energy Choices: Investing in a Strong Economy and a Clean Environment*. Cambridge, Mass.: Union of Concerned Scientists. December.

USEPA. 1980. *Passenger Car Fuel Economy: EPA and Road.* Report EPA 460/3-80-010. Ann Arbor, Mich.: U.S. Environmental Protection Agency. September.

Vyas, A., Argonne National Laboratory, Argonne, Ill. 1990. Personal communication. December.

Williams, R. H., E. D. Larson, and M. H. Ross. 1987. "Materials, Affluence, and Industrial Energy Use." *Annual Reviews of Energy* 12:99–144.

Womack, J. P., D. T. Jones, and D. Roos. 1990. *The Machine That Changed the World.* New York: Rawson Associates.