Energy and Environmental Research Needs

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A High Priority National Program Area (HPNPA) is being developed by FHWA for research on the efficiency of future national transportation systems. This research will be conducted over 5 years and will target highway system planning and management in congested urban areas and development of data systems and analytical methods for use in financial planning, highway system planning, and environmental and economic analyses.

The research will focus primarily on solutions to urban congestion, the abundant use of oil, and air quality problems (*1*, pp. 7, 9).[1] The research agenda will look at a common component of these problems: the interaction between land use and transportation. The contributions of land use and urban form to the pressing transportation problems of congestion, energy use, and air quality are not well known. The goal of this research program is to identify short-term and longer-term strategies to reduce congestion, energy use, and air pollution by strengthening the connection between land use planning and transportation.

This paper draws on the resource papers, background literature, workshop reports, and discussion from this conference and on outside research to identify a potential research agenda in the area of energy and the environment. The objective is to understand how the urban transportation-land use planning and decision making process could be improved to achieve national energy efficiency and environmental objectives while meeting urban mobility needs.

One bias must be disclosed at the outset. This conference identified a significant gap in adequate data bases and models for research. In some cases transportation planners are using models based on demographic data collected in the 1960s. Two types of data needs were identified:

1. Baseline data on demographics, mode choice, travel characteristics, and so forth that can be used in new travel forecasting models and
2. Behavioral data that analyze how specific measures taken to promote a public policy objective succeed or fail in achieving that objective.

Research focusing on problem-solving and evaluation rather than on developing new simulation models that have no particular ability to inform public policy decisions is favored in this paper. Research to inform decision making in five areas involving the construction and use of national transportation infrastructure is particularly timely. These areas are as follows:

1. **Trip generation decisions:** These are decisions made by individuals about where to live and work, whether to make a trip, and what mode to use. The presumption is that information on the energy and environmental costs of such decisions, if made known to transportation consumers and charged back to them at marginal cost, would influence their behavior.
2. **Investment decisions:** These are decisions made by responsible elected officials and transportation professionals to invest in particular transportation solutions. The presumption is that information on the effects of such decisions on transportation demand, energy, and environment and on total environmental and energy costs would affect these decisions.
3. **Finance decisions:** These are decisions made by federal, state, and local officials on how to assess the costs and benefits of transportation services and improvements among various users. They include decisions to tax, toll, or subsidize certain transportation-related services and address how these decisions affect energy efficiency and the environment.
4. **Land use–planning decisions:** These are decisions made by local and regional officials (mostly elected but some agency officials) on whether and how to regulate certain land uses based on the ability of existing and potential future transportation capacity to serve those uses and the energy and environmental consequences of such decisions.

5. **Project decisions:** These are decisions made by land developers to proceed with land development projects on the presumption of availability of sufficient transportation infrastructure to support such projects and the energy and environmental consequences of such decisions.

Almost all of the research needs relating to energy and environmental issues identified at this conference and discussed in the workshop reports seek to inform one or more of these five types of decision making. By dividing energy and environmental issues among these various types of decision making it is hoped that the research protocols developed for environment and energy issues as a result of this conference will place great emphasis on the ability of research results to inform real-world decision making. By making the connection between research and decision making, this new FHWA High Priority Program will significantly strengthen the linkages between transportation, urban form, and the environment.

PROBLEM STATEMENT

A healthy transportation system is vital to national well-being, no less than a healthy circulatory system is vital to personal well-being. A strong, balanced, and interconnected system of rail, highway, transit, air, water, bicycle, and pedestrian facilities supports a strong, balanced, and efficient domestic economy while also improving the ability to compete in international markets. The national interest clearly is served through the development and maintenance of a sustainable program for the delivery of transportation services that strengthens national and international competitiveness, maintains national security, promotes the achievement of national clean air goals, enhances energy efficiency, and improves the overall quality of life.

Unfortunately, transportation is also a heavy consumer of natural resources, particularly land and energy, and can also degrade air quality.

Land

Low-density development increases transportation energy demand, air pollution, vehicle miles traveled (VMT), and natural resource consumption (*2–4*). For example, the California State Highway Division calculates that single-family residences on 1/2-acre lots generate 12.5 car trips per day, whereas such development on 1/8-acre lots generates 8.5 car trips per day (*2–4*). Nevertheless, land densities are

declining (*5*, p. 2). For example, in the Chesapeake Bay area, the average developed acreage per capita in 1950 was 0.18, but had increased to 0.65 by 1980. This means that average densities declined from more than five people per developed acre to fewer than two (*5*, p. 2). Within urbanized areas, both residences and work places are dispersing from the classical concentric configuration to sprawling low-density development (*6*, p. 2). Despite sprawl, length of work trips is decreasing (*2*, Table 10, p. 32). The percentage of all work trips that were less than 6 miles increased from 52.2 percent in 1969 to 54.1 percent in 1983 (*2*, Table 10, p. 32). Work trips account for less than 25 percent of local automobile trips in urbanized areas and less than 30 percent of total VMT (*6*, p. 2). However, work trips contribute disproportionately to energy and environmental costs because of their concentration in peak travel periods and the fact that they are characterized by very low occupancy ratios: 1.15 people per car compared with 1.7 for the average car on the road (*7*, p. 20).

Energy

Per capita gasoline consumption in U.S. cities is nearly 4.5 times higher than in European cities and 10 times higher than in Japan. Despite new car fuel efficiency gains, automobile travel consumes 40 percent more oil now than 15 years ago. Approximately 68 percent of all vehicle trips operate on the urban driving cycle (less than 30 mph average) (*8*). Fuel consumption doubles when speed drops from 30 mph to 10 mph (*9*). Transportation accounts for more than 63 percent of total domestic oil consumption, most of it to fuel private automobiles. If energy costs to build infrastructure, produce fuel, and manufacture vehicles are included, transportation accounts for 72 percent of total domestic oil consumption (*10*). Today half of U.S. oil is imported; by 2010 the U.S. Department of Energy projects that oil imports will amount to 70 percent of demand, mostly for transportation (*11*).

Air Quality

Motor vehicles account for 25 percent of all U.S. emissions of CO_2, a primary greenhouse gas, and 16 percent of U.S. emissions of chlorofluorocarbon, another greenhouse gas and a primary destroyer of the ozone layer, and they indirectly contribute to buildup of methane and tropospheric ozone through emissions of nitrous oxides and CO (*1*, pp. 7–9). (Tropospheric ozone and methane also contribute to the

greenhouse effect.) Increases in VMT have overwhelmed progress in reducing tailpipe emissions: 27 additional cities violated national ambient air quality standards (NAAQS) for ozone in 1988. More than 100 cities now violate ozone standards; 44 violate CO standards (*12*, p. 6). (Transportation sources account for approximately two-thirds of U.S. CO emissions.) Congestion exacerbates air pollution problems, yet VMT is projected to increase 45 percent by the year 2010, whereas highway capacity will only increase 6 percent.

Urban areas bear the brunt of these problems, yet the interest in clean air, energy security, and natural resource protection elevates these problems to a national level. Solutions to these problems will require unprecedented cooperation at all levels of government as well as technological improvements and efficient pricing of transportation services to change personal transportation habits.

CREATING A DECISION-BASED RESEARCH AGENDA

Research, to be useful, must inform decision making. High-priority areas for research, broken down by decision making area, include trip generation decisions, investment decisions, finance decisions, planning–land use regulation decisions, and project decisions.

Trip Generation Decisions

Obviously, the decision that has the greatest ability to minimize transportation-related energy consumption and pollution and to reduce congestion is the decision of whether and how best to make the trip. (In one of the workshops at this conference, it was discussed whether, if a car was invented that emitted no pollution and consumed no fossil fuels, there would still be concern about urban form. The consensus was yes, because of other problems, such as congestion, land consumption from sprawl, infrastructure costs, etc.) What research is needed to inform individual decisions on these two important questions? Changes in consumer behavior are predicated on choice. If consumers have no choice in the process of trip selection, no behavior changes are possible. Therefore, research focused on strategies to reduce the energy and environmental impacts of urban form must focus on how to provide a sufficient range of energy-efficient and nonpolluting transportation choices, given a consumer's mobility needs. Options include the following.

Total Internalized Trip Cost

What are the total costs of particular types of trips (e.g., commuting, recreation, shopping) by vehicle occupancy and trip length? New models are needed to include not only the marginal and fixed costs by mode but also costs for lost productivity paid in time spent in congestion. All costs paid by the user (e.g., in dollars, time, and equipment maintenance) should be included in this calculation.

Total Externalized Trip Cost

What are the total societal costs of these same trips? A new system of accounts is needed to include deferred maintenance of existing transportation infrastructure as well as costs in pollution, energy waste, health, and so forth. The presumption is that if individuals knew the true cost to society of their trip and modal choices, such knowledge would influence their behavior even if they were not individually charged for such costs.

Allocation Mechanisms

Research is needed on methods to allocate the societal costs of mobility to those responsible for the costs (*7*, p. 41). (One researcher puts these externalized costs at $260 billion per year, or about $2.53 for every gallon of fuel consumed.) The presumption is that if all true costs were charged back to the user, fewer energy-intensive and highly polluting trips would be taken.

Telecommuting

Telecommuting has not achieved the results hoped for 10 years ago in reducing VMT, pollution, and energy consumption by reducing the need to travel. Why not? Is telecommuting simply shifting travel to different times of day? Is telecommuting a potentially effective transportation demand management (TDM) strategy? What additional information or service needs do consumers need to make it work?

Land Use and Trip Generation

What land use patterns are most efficient in serving total mobility needs? What densities and development characteristics support

which modes? Household characteristics, as well as a simple measure of units per acre, must be considered, given the vastly changed household demographics in the past 20 years (i.e., reduction in persons per household). What types of mixed uses minimize travel demand? Case studies of communities such as Davis, California; Portland, Oregon; and Boulder, Colorado, may be helpful (*13*). Is single-use zoning a mistake because of its heavy demand on transportation services? What are some successes and some failures of single-use and mixed-use zoning? What are the salient factors to consider?

Reducing Discretionary Travel

Between 1969 and 1983 commuting declined from 33.6 percent to 30.1 percent of household VMT, whereas discretionary VMT (shopping and personal business trips) increased from 19.3 percent to 30.4 percent of household VMT (*14*, p. 3; *15*). What accounts for this significant growth in discretionary VMT and what role do transportation–land use interactions play in this growth?[2] Do any data later than those for 1983 exist?

Investment Decisions

The people who decide how a region is to grow are the people who decide land use and transportation. Unfortunately, the same people do not always make both types of decisions. Land use decisions are made by local elected officials and zoning boards or, in locations without any land use regulation, by private developers. Transportation investment decisions, particularly for large capital projects requiring federal or state assistance, are made by regional or state bodies and agencies. Often the decisions of these regional and state agencies are influenced more by the laws and regulations under which they operate (which regulate the amount of available dollars for transportation investment and the manner in which they can be disbursed) than local needs. The result is a mismatch between transportation and land use decision making that results in inefficient and polluting transportation–land use networks.

The lack of connection between transportation and land use decision making has become more pronounced as federal laws mandating improvement in urban air quality are strengthened. Research is needed to allow a fuller understanding of the nature of the potential conflicts among transportation, air quality, and land use planning and

of how federal and state transportation polices and programs can exacerbate or resolve these conflicts. Possible legal and regulatory solutions must also be reviewed. Some appropriate areas of research are discussed below.

Update The Costs of Sprawl

In 1974 the U.S. Council on Environmental Quality published a book entitled *The Costs of Sprawl (16),* concluding that automobile-related pollution would be reduced significantly in planned developments and that the economic and environmental costs of high-density development were significantly lower than those of low-density development. Significant methodological deficiencies have been identified in this study. A new baseline study is needed to inform regional and statewide transportation and planning officials of strategies to integrate transportation, land use, and clean air planning. In particular, research is needed on (a) how land use decisions drive transportation demand; (b) how transportation investment decisions drive land use decisions; (c) how geographic information systems (GIS) technology could be used to integrate transportation, land use, and air quality planning, particularly in the development of long-range transportation plans; and (d) the costs to the public of uncoordinated transportation, land use, and clean air planning.

Study Growth Management

Policy options available for public action to manage growth and link land use decisions to capital transportation investment decisions are becoming more numerous. Studies are needed of state and local growth management plans and ordinances in Oregon; Washington; Maine; Rhode Island; Vermont; New Jersey; Georgia; Montgomery County, Maryland; and Florida, as well as trip reduction ordinances (TROs) in the South Coast Air Quality Management District of California and elsewhere (*17, 18*).[3] Specifically, how successful have these laws and ordinances been in shifting transportation investment decisions to favor more energy-efficient and more pollution-free solutions?

Perform Needs Assessment

At this conference it was generally agreed that planning and investing in transportation projects to achieve a certain level of service (LOS)

is no longer an adequate criterion to serve regional needs. Although LOS is a measure of relative congestion, certain areas actually plan for a low LOS as "traffic calming" measures to protect neighborhoods, reduce VMT, increase pedestrian activity, and promote clean air. In other areas, where improvements to traffic flow are clearly needed, the expansion of roadways to improve LOS may not be feasible. If LOS is not the measure for assessing transportation need, what is? What mediating structures exist to reach political consensus on a transportation mission at the metropolitan planning organization (MPO) level and on strategies to promote that mission?

Measure Air Quality Improvements

The Clean Air Act Amendments of 1990 place significant new constraints on transportation projects in nonattainment areas to actively promote the achievement of NAAQS (*19, 20*).[4] Yet few data exist to measure the ability of any specific transportation project to promote clean air goals by achieving specific mobile source emission targets. Research is needed to assist MPOs in measuring the ability of specific types of TDM and transportation system management (TSM) strategies and new transportation investments to meet real, quantifiable NAAQS targets.

Integrate Planning with Funding

Regardless of how well transportation, land use, and air quality planning is conducted at the MPO level, often federal and state transportation funding restrictions override good planning and direct funds to projects inconsistent with regional goals. Research is needed on how to bring planning and funding decisions together to achieve regional air quality and energy efficiency goals.

Apply Least Cost Planning

Efforts to manage demand and to provide for new demand through "least cost" methods have met with significant success in the electric utility industry. However, the decision making structure is much less fragmented in the utility industry (most electricity is generated from large central generating facilities). Also, there is relative uniformity between sources of electricity, whereas transportation is differentiated by mode (e.g., bicycle versus car), by quality of experience (e.g., Volkswagen versus Cadillac), and by trip length (e.g., a 5-mile trip may

provide several modal choices, but a 20-mile trip may provide only one modal choice). Is it possible to apply the "least cost" planning model to the transportation sector while accommodating individual choice by mode, experience, and trip length (*21*)?[5]

Study Retrofitting

How do transportation investment alternatives vary in relation to the state of urban development? Are different models needed depending on whether population is growing, stable, or shrinking? Do alternatives vary depending on whether decision makers are trying to change the form of a built, mature city or trying to control future growth of a young city?

Finance Decisions

Both pricing and financing of transportation projects have a dramatic effect on what gets built and maintained. Who benefits? Who pays? These are two important questions with significant consequences in mode selection, land use patterns, and investment decisions. Research items that emerged at this conference are discussed below.

Fiscal Zoning

As bedroom communities grew up around major cities over the past 30 years, suburban officials were hard pressed to provide water, sewers, roads, schools, fire protection, and other services for these communities. The result was the adoption of favorable zoning laws to attract the retail and commercial base needed to support (in sales and property taxes and assessments) the cost of municipal services. This drained older cities of their commercial base and encouraged urban sprawl. Research is needed to understand this problem and to evaluate alternative solutions, such as tax-base sharing, to reduce energy-intensive and highway-intensive land use patterns. (Ironically, according to one conference participant, the land use that generates the greatest total public revenue is the strip-zoned automobile mart consisting of automobile dealerships and automobile repair services.)

Private Financing

The decline of general revenue sources in relation to growing travel demand is increasing pressure to assess the cost of transportation improvements on private developers in the form of fees, assessments,

and proffers. Private funding for transportation improvements is totally disconnected from planning, because planning is designed only to guide the investment of public transportation dollars. Research is needed to assess the threat private financing poses to land use planning and to design solutions that promote energy efficiency and air quality.

Parking

More than 75 percent of all employee parking is provided free. Employers can deduct the full cost of providing employees with free parking from taxes, although the same employer can deduct only $15 per month for providing employees with free transit passes. Of course, parking is not free; costs are simply shifted from the user to the public in reduced tax revenues and higher infrastructure costs. Research is needed on the public costs of employer-provided free parking, not only in dollars but in energy use, land use, and pollution. Alternative parking management strategies and parking limitations to reduce home-to-work car commuting should be investigated. One strategy that deserves special investigation is the South Coast Air Quality Management District plan to have employers pay a commute allowance to all employees and then charge an equivalent amount for parking.

Gas Tax/Carbon Tax

The United States has the lowest gas tax of any industrialized country, the highest absolute number of registered motor vehicles (185 million), and the highest number of vehicles per licensed driver (1.03) and accounts for fully 50 percent of the world's VMT. Yet VMT is growing at a rate of 3 to 6 percent per year in most urban areas, far outpacing the ability of the transportation infrastructure to accommodate such growth. Research is needed on the connection between energy price and vehicle use. How important is energy price to modal choice? What is the price elasticity of transportation energy demand? At what price do alternative fuels become economically feasible? What is the range of public policy options at the federal, state, and local levels to use fuel pricing to achieve public policy objectives in coordination with transportation and land use planning?

Mortgage Interest

The home mortgage interest deduction has dramatically increased demand for single-family homes, thus greatly influencing land use

patterns and, consequently, demand for transportation services. Reduction or elimination of this tax benefit is unlikely in the foreseeable future. However, research on the connection between this public policy, land use, and transportation demand is needed.

Land Taxes

Many transportation improvements are promoted not to meet existing demand but to serve new development. Private financing of these projects is one strategy for imposing the costs of such improvements on the developers who primarily benefit from these projects. (A project that has received national attention as a model for private financing of a major highway improvement is the Dulles Access Road Extension in Loudon County, Virginia.) Alternative strategies for capturing the value of transportation improvements are needed. Levying a special capital gains tax to capture the increase in land values resulting from transportation improvements may be a way of financing future transportation while keeping the planning and funding decisions within the public sector and connected to regional energy and environmental goals. This strategy has been adopted with apparent success in Europe. Research is needed comparing the European model with the private financing model in relation to regional energy, environmental, and land use objectives.

Price Goods Movement at Marginal Cost

Approximately 50 percent of urban transportation is for the movement of goods, not people.[6] Research is needed on how to charge back to freight haulers the marginal cost (both economic and social) of their use of urban transportation systems.

Planning and Land Use Regulation

Land use and transportation planning converge at the regional level. New governmental structures, such as regional zoning authorities and special transportation districts, are being formed to allow elected officials to address the problems of transportation, urban form, and the environment at the regional level. These new agencies and strategies hold some hope for the promotion of regional air quality and energy efficiency goals. Research needed to inform decision making at this level includes the following topics.

Urban Boundaries

Land use planning designed to fight "hopscotching" and isolated development and to direct urban growth inward can have dramatic effects on regional VMT growth and transportation energy demand while improving mobility (*22*). An ordinance designed for just this purpose has been enacted in Portland, Oregon. A case study of the "urban boundary" concept is needed as well as an analysis of its ability to promote energy efficiency and air quality.

Demand Management

Much research has already been conducted on TDM and TROs (*17, 18*). However, more research is needed to identify both alternative institutional arrangements needed to ensure adoption and implementation of these measures and the policy instruments needed to encourage these arrangements to develop (*14*, pp. 8, 9).[7] TDM and TRO measures alone will not work; they must be backed up with policies, programs, interagency agreements (memorandums of understanding), reporting structures, support structures, economic incentives, and possible sanctions. A compendium of such policies and a survey of such institutional arrangements are needed. In particular, policies that establish substantive TDM or TRO objectives should researched, such as the following:

1. **VMT growth caps:** Ottawa, Canada, and Boulder, Colorado, have set absolute VMT growth caps in their long-range transportation plans. How extensive is this practice throughout the nation?
2. **Parking caps:** Caps on parking spaces as a ratio of retail floor space are one option. Other parking limitation equations should be studied as well for their ability to reduce VMT and encourage mode shifts.

Congestion Management

Smart highways, high-occupancy-vehicle lanes, flow improvements such as reversible lanes, and other TSM improvements are all possible strategies to increase highway capacity and reduce congestion in the short term. However, little is known about the effect of such strategies on urban land use and total travel demand in the long term. There is some evidence that such strategies, if not coordinated with land use planning, simply encourage users to take longer trips, thus

increasing total VMT, pollution, and energy use. Research comparing the relative ability of TSM and TDM strategies to achieve regional energy, environmental, and land use objectives is needed.

Corridor Preservation

Transportation planning traditionally accommodates future transportation growth based on a static land use plan. No attempt is made to influence future land use patterns to channel future transportation demand toward underused transportation corridors, such as abandoned rail corridors, and to encourage the preservation of such corridors for future transportation uses. Research is needed on ways to integrate transportation and land use planning to make maximum use of the existing transportation infrastructure to serve future transportation needs and on strategies to preserve abandoned railroad corridors and other transportation infrastructure for future transportation use.

Methodological Issues

Most transportation modeling programs (e.g., EMME2) do not integrate land use policy changes over time into projections of future transportation demand, distribution, or traffic flow. Alternative methodologies are needed that integrate land use and TDM strategies as dynamic variables in the modeling process. Specifically, methodologies are needed to allow analysis of alternative land uses in the alternatives analysis section of project-level and plan-level environmental impact statements (EISs).[8]

Methodologies are also needed using GIS and computer-aided mapping to integrate air quality, transportation, and land use planning.[9]

No federal, state, or local standards of performance exist for transportation energy efficiency. Methodologies should be developed to establish such standards (e.g., BTU per passenger mile), as well as mechanisms for measuring and enforcing such standards over time.

Air quality models for future transportation systems at the long-range plan level do not integrate the effect of subsequent transportation improvements occurring between plan creation and construction and tend to ignore land use decisions in the region they are likely to affect. Yet the Clean Air Act Amendments of 1990 require transportation planning to demonstrate absolute progress toward achievement of NAAQS over time. Transportation and air quality modeling must be integrated to assure absolute progress toward achievement of NAAQS as the plan is implemented.

The ITE *Trip Generation Manual* (*23*) does not take TDM strategies, such as parking price and availability, into consideration in its traffic forecasting models. This results in inflated traffic forecasts that are then used to justify projects that may not have been required if TDM and TSM strategies were adopted. A major overhaul of the *Trip Generation Manual* (*23*) is needed, as is research in support of an improved manual.

Modal Split

Rather than planning to achieve a particular LOS within a region, how feasible is it to model the energy and environmental impacts of alternative modal splits at a given level of total transportation use (mobility?) in the future? For example, Boulder, Colorado, has adopted a plan to achieve zero VMT growth and a 15 percent bicycle share of the modal split for peak commuting period by the year 2000. How extensive are such standards in transportation planning and goal-setting? What variables most affect modal split? Can they be quantified and incorporated in alternative regional transportation plan models?

Project Decisions

Decisions by public decision makers to invest public funds in transportation infrastructure were addressed in the section entitled Finance Decisions. This section addresses research needs to influence private decision makers, primarily developers, in deciding where to develop, how to provide adequate transportation services to the development, and how to design the development to minimize energy and environmental impacts. Some salient research items include

- How should land use be configured in developing areas to reduce travel demand?
- How big a barrier are zoning and subdivision ordinances and street design criteria to the integration of park and ride facilities, paratransit, bicycles, and buses into project designs? For example, do minimum turning ratios for fire engines in subdivision ordinances eliminate the possibility of bicycle lanes or sidewalks? How can these local requirements be adjusted to encourage a maximum range of modal choices?
- What are appropriate site development standards to address pedestrian, bicycle, and transit availability? What potential exists to

encourage these alternative transportation modes through such standards? Where are the modal standards? How successful have they been in achieving their objectives?

- Is there an ideal size for shopping malls to achieve energy efficiency as a VMT generator?

The city of Davis, California, puts an 8-acre limit on new shopping malls. What is the basis for this limitation? What effect does it have on the secondary energy and environmental impacts of mall development?

CONCLUSION

The research agenda for transportation, urban form, and the environment could be expanded indefinitely. However, the problems of urban congestion, air pollution, global warming, and energy security must be addressed now. This conference and the research agenda being developed by the FHWA High Priority Planning Program are a welcome initiative to all who are interested in the energy and environmental impacts of the present transportation infrastructure.

The focus of the research agenda on urban areas and, in particular, on the role of urban form (land use) in advancing or defeating national energy and environmental objectives is extremely timely. The experience of the 20 years since the Clean Air Act was enacted in 1970 demonstrates that tailpipe emission controls and stationary source controls alone will not achieve NAAQS. Mobile source controls that focus on the need to use the private automobile and that provide transportation consumers with choice among modes must be addressed. Such choices cannot be developed fully without integrating urban form and land use considerations into transportation and air quality planning.

Energy considerations are also increasing in importance as the percentage of total domestic oil consumption derived from imported oil creeps over 50 percent. Transportation accounts for fully 63 percent of total domestic oil consumption directly as fuel and 72 percent of total domestic oil consumption, if the cost of refining and transporting fuel and the energy cost of building and maintaining our transportation infrastructure are taken into account. Essentially all (97 percent) transportation fuels are petroleum-based. Global warming is a direct result of the burning of fossil fuels, primarily oil and coal. Indeed, questions of national energy security and global warming cannot be dealt with if transportation is not addressed.

This research agenda is a welcome start in the attempt to integrate transportation, land use, and air quality planning to promote national energy and environmental interests. It comes not a moment too soon, and will receive the full support of the national conservation and environmental community.

NOTES

1. Although the HPNPA focuses on air quality and urban traffic congestion as driving the need for research on ensuring the efficiency of future transportation systems, it is likely that global warming will become an increasingly important force in focusing future transportation research on demand reduction strategies and the transportation/land use connection. Motor vehicles currently account for 25 percent of total U.S. carbon dioxide (CO_2) emissions and 67 percent of total U.S. carbon monoxide (CO) emissions (*1*, pp. 7, 9).
2. Michael Replogle has done some work in this area (M. Replogle, unpublished data). Preliminary data indicate that more home-to-work trips are linked trips (e.g., shopping, dropping children off at day-care) as well as the work commute. Statistically, these are discretionary trips but actually they are work trips. The growth in linked trips increases automobile dependency because they involve several destinations. Mixed-use land patterns that allow more pedestrian solutions to these trips (e.g., dropping children off at day-care close to home on the way to the bus) should be researched as a means of reducing automobile dependency.
3. FHWA published a *Status of Traffic Mitigation Ordinances (17)* and an *Evaluation of Travel Demand Measures to Reduce Congestion (18)*, but these studies do not link specific strategies to the achievement of specific air quality standards or reductions in congestion levels. More research on measurable results is needed.
4. In the Clean Air Act Amendments (*19*), for the first time Congress established substantive air quality objectives for transportation plans and linked federal funding for transportation projects to the adoption of regional transportation plans containing quantitative mobile source emission targets. Under previous U.S. Department of Transportation interpretation of Clean Air Act and Federal Highway Act "conformity" rules, transportation projects had only to demonstrate that they did not actively prohibit implementation of transportation control measures (*19, 20*).
5. Of course, "least cost" means least *total* cost, including social and environmental costs. One of the greatest difficulties in applying this principle to transportation is the difficulty encountered in quantifying these costs and comparing them with total benefits. The challenge of such a methodology was clearly laid out by McHarg (*21*, p. 32):

> The objective of an improved (transportation planning) method should be to incorporate resource values, social values, and aesthetic values in addition to the normal criteria of physiographic, traffic and engineering consideration. In short, the method should reveal the highway alignment having the maximum social benefit and the minimum

> social cost. This poses difficult problems. It is clear that new considerations must be interjected into the cost-benefit equation and that many of these are considered non-price factors. Yet the present method of highway cost-benefit analysis merely allocates approximate money values to convenience, a commodity as difficult to quantify as either health or beauty.

McHarg wrote this at the time of the enactment of the National Environmental Policy Act (NEPA), which attempted to inform decision making in just this fashion. The relative inability of NEPA to apply the least total cost concept to transportation decision making has led to renewed interest in this concept. The Natural Resources Defense Council and the Conservation Law Foundation of New England have conducted research on application of the least cost principle to transportation planning.

6. This figure comes from Workshop No. 2 (Wickstrom) and is attributed to Ken Ogden of the University of California, Irvine.
7. This research recommendation comes from Hillsman and Southworth (*14*, p. 9). They point out that what is understood about individual transportation demand involves mode choice rather than the decision or need to travel. Research focusing on the travel decision itself is a high priority (*14*, p. 8).
8. Proposals contained in the administration's Surface Transportation Act Reauthorization would delegate EIS responsibilities to states for the Federal Aid Urban and Rural Programs (a combined program in the proposal). Guidance on integrating land use and transportation planning in EIS documents should be a top priority if such proposals are adopted, because few states will have any experience in this area.
9. Although the use of GIS in transportation and land use modeling is in its infancy, some good work has been done (M. Replogle, unpublished data).

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