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NUTS AND BOLTS: The Implications of Choosing Greenhouse-Gas Emission Reduction Strategies

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EXECUTIVE SUMMARY

Most global warming discourse has centered on debates about whether the United States should adopt a strategy to reduce greenhouse gas emissions, and, if so, by how much. Less attention has been paid to specific policy tools that would be used to implement a greenhouse-gas reduction strategy. Specifically, what would energy-conservation measures and greenhouse-gas reduction measures cost?

Shortly after taking office, President Clinton announced that his administration would pursue a global warming policy designed to reduce greenhouse-gas emissions to 1990 levels by the turn of the century. Now that his administration is crafting plans to promote widescale energy conservation, these latter issues will move to the forefront in the policy debate.

Two different kinds of policy tools currently are receiving attention from policymakers. On the one hand are pricing strategies such as air emission charges (including proposals for carbon charges). On the other hand are command-and-control approaches whereby legislators and regulators would require (or directly promote) use of specific energy-conservation technologies and practices. Both kinds of tools, designed primarily for the purpose of reducing greenhouse-gas emissions, could involve significant economic costs. For example, a charge of $100 per ton of carbon would result in a doubling of fuel costs from 1989 prices.

Command-and-control conservation strategies, now favored by many environmentalists, could potentially be even more costly, depending on the particular policy options. In general, these conservation proposals are technologically oriented rather than focused on individual behavior patterns. This tendency probably arises from wishing to avoid the political pain of having to tell people that reducing energy use is not a “free lunch.”

While enhanced conservation investment may produce some net benefits, these gains are unlikely to be as substantial as proponents estimate. Policies requiring increased fuel efficiency standards for automobiles, increased mass transit, or mandatory use of alternative fuels will likely have limited impacts in reducing energy consumption or vehicle emissions while imposing high costs. For example, the price of oil may have to rise above $30 per barrel (40 percent over current prices) before many alternative fuels would be cost-effective.

If global climate change does not materialize, pursuing all-out reduction efforts for little or no gain could cripple the economic development of future generations. Both market-oriented and command-and-control measures based on a single-purpose strategy of reducing greenhouse-gas emissions are likely to be costly, since both types of measures would introduce significant changes in current energy-consumption patterns without any certitude that the targeted emissions are currently having any adverse impacts.

On the other hand, an energy policy based on conveying market price signals about resource use, energy consumption, and air emission impacts would promote decentralized decision-making in which individuals make their own adjustments to price information. This enables individuals and firms to find the most-efficient responses to changing cost structures.

I.INTRODUCTION: PLUMBING THE DEPTHS OF GLOBAL WARMING POLICY

Environmental groups, scientists, and policymakers continue to dispute the impacts of increased greenhouse gas concentrations in the Earth's atmosphere. Likewise, debate continues regarding the appropriate policy responses in this context of scientific uncertainty. The most visible and widely followed debate centers on the scientific evidence about predictions for global warming. Is warming occurring? If so, how much and with what consequences? This controversy has not been resolved and will persist for the foreseeable future.

Amidst this uncertainty, policy debate has focused on the appropriate speed and scale of response. On one hand, some argue for a “wait-and-see” approach in which we gather more evidence about potential global climate change and the various proposed responses. At the other end of the policy spectrum stand those advocating a “save-the-day” all-out effort to eliminate greenhouse gas emissions as rapidly as possible in order to mitigate to the maximum extent any threat from global climate change. Lying between these two are “no regrets” policies directed at improving energy efficiency or reducing other air emissions, with carbon dioxide (CO_2) emission-reductions emerging as a side effect of these other efforts that have clearer and better understood benefits.

While policy discourse has centered on debates about the appropriate greenhouse-gas reduction target, less scrutiny has been given to how these goals might be pursued. This concern centers not on the policy goals—for example, whether and how much to reduce air emissions—but rather on the policy tools—for example, what policies can most cost-effectively bring about increased energy efficiency and/or greater reductions in air emissions, including CO_2 emissions.

This discussion of specific policy proposals has become particularly relevant with passage of the 1992 Energy Policy Act[1] and the release of President Clinton's greenhouse gas-reduction plan in October 1993. Sound policy-making should rest on an understanding of policy costs and likely effectiveness in generating benefits.

The discourse about appropriate policy tools, which is not unique to global warming, has two main opposing views. On the one hand are those who argue that reductions in greenhouse gas emissions (or other air emissions) can best be achieved through legal mandates and technological “fixes.” On the other hand are those who argue that given properly priced resources, economic incentives and disincentives will influence individual choices to yield hoped-for reductions in air emissions (and/or increased energy conservation) most cost-effectively.

Finally, another layer of debate complicates global warming policy discussions. In examining policy effectiveness, an important pragmatic issue is whether effective policies can be implemented at the local, or even national, government levels to temper a threat of global warming.

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[1] See “Title XVI-Global Climate Change,” *Energy Policy Act of 1992,* H.R. 776, October 24, 1992.

Those debating the expected impacts from various policy instruments—the more technical layer of policy formulation—can be divided into two categories, although the boundary is fuzzy. One group, rooted largely in economics, assumes that individuals (and firms) generally make efficient choices in the marketplace if prices reflect actual resource scarcities and pollution-mitigation costs. The other group argues that the conditions necessary to make markets work efficiently generally are absent. Instead, other institutional mechanisms, such as laws mandating investment or consumption choices, are required to correct these failings and to achieve emission-reduction goals.

A growing attention by the public to environmental issues further complicates the policy decision-making process. In particular, public misperceptions about environmental matters sometimes impel policymakers to push for measures that will yield few real additional benefits. For example, in the San Francisco Bay area, while a key indicator of air quality improved about 60 percent over the 1984 to 1992 period, public opinion polls showed the percentage of respondents who believed that air quality is getting worse increased from about 40 percent to over 60 percent.[2] Politicians have found that they may gain voters' goodwill by emphasizing their intent to "help" the environment, but they face the dilemma of choosing between actions that experts claim will yield real benefits versus supporting measures that the public can clearly perceive. In this context, how policy choices are communicated and the degree of commitment to carrying them out may be just as important as the analyses behind the choices.

II. PERSPECTIVES ON THE DEBATE

Policy choices are a large degree dependent on assumptions about the ability of institutions and individuals to rapidly adjust their behavior, and at what cost. Depending on these assumptions, one person's no-regrets policy can be another's save-the-day nightmare. Evaluating the expected outcomes of these proposals requires not only a compilation of direct societal costs of the policy, but also an understanding of the various perspectives at play.

Essentially, two general perspectives characterize discussions about greenhouse gas-reduction strategies: one is chiefly held by "economists," the other is generally supported by some "technical experts" and "environmentalists," who collectively might be called "conservationists."[3]

[2] "Perception vs. Reality," *Service Matters*, No. 3 (San Francisco: Association of Bay Area Governments, January/February 1993), p. 6.

[3] Broad generalizations are used herein for illustrative purposes; obviously the views of individual economists, scientists, and environmentalists vary widely. For a full discussion between the scientists' and economists' perspectives, see two papers commissioned by the California Energy Commission: James E. McMahon, *Imperfect Markets and Energy Efficiency*, Energy Analysis Program, Energy and Environment Division, Lawrence Berkeley Laboratory, prepared for the California Energy Commission, Sacramento, Calif., July 9, 1992; Ronald J. Sutherland, *Market Barriers, Market Failures and Energy Issues*, Argonne National Laboratory, for presentation to the California Energy Commission, Sacramento, Calif., July 23, 1992.

·Many economists believe that the existing economic system is in a self-adjusting equilibrium, and interventions in the status quo will result in net *increases* in social costs.

·Conservationists, on the other hand, believe that the existing market-oriented economic system has a number of failings that inhibit the ability of individuals to choose the most cost-effective and beneficial investments. These "market failures," they contend, are so pervasive that a range of new technological and behavioral "fixes"—renewable resources and a conservation ethic—could be imposed that would actually *decrease* costs to society while reducing pollution.[4] They point to the "energy conservation paradox"—that many efficiency-improving measures have not been adopted despite apparent cost-saving potential—as proof of these market failures.[5] From this view, government intervention is needed to help direct the decision-making abilities of individuals.

For economists, a "no-regrets" policy *only can be achieved if well-established environmental benefits—reduced air or water pollution, for example—offset any higher costs associated with the new policy direction*. For conservationists, the greenhouse gas-reduction strategies that promote conservation are assumed by definition to bring benefits that translate into lower costs and are, thus, by their very nature "no regrets."

[4]In economic parlance this view may be summarized by the notion that the current "equilibrium" is "inefficient," thereby creating an "efficiency gap." See, for example, Darwin C. Hall, "Global Warming Economics: Faulty Timing, and Omission of Social Costs and Energy Alternatives," *AERE Newsletter,* May 1993, vol. 13, no. 1, pp. 17–20.

[5]Avraham Shama, "Energy Conservation in U.S. Buildings, Solving the High Potential/Low Adoption Paradox From a Behavioral Perspective," *Energy Policy,* June 1983.

Economists versus Conservationists: Two Views of Markets

Many scientists or engineers understand the data and techniques—and issues of uncertainty—behind global warming forecasts. However, this discipline tends to have a bias towards implementing new technology to resolve problems. Environmentalists frequently have legal or sociologically based training that tends to discount behavioral responses to economic stimuli. Instead, they believe that appropriate outcomes are best guaranteed by rules that dictate individual action. Because many conservationist proponents of rule-based action assert that the "real" social cost of money—the interest or discount rate—is lower than what private enterprises and individuals pay, they believe that the government should dictate day-to-day investment and purchasing decisions normally done by individual managers and consumers. The shortcoming in this approach is its failure to recognize how people adapt to new technologies in ways that can be unforeseen by the original innovators. For example, imposing new efficiency standards and expecting to capture 100 percent of the savings fails to adequately account for likely consumers' and producers' responses which may lead to lower savings levels.

Economists argue that regulators cannot adequately anticipate the responses by individuals to laws and innovations and that the final choice of actions should be left to these individuals. However, the assumptions used by many economists may oversimplify the complexity of the issue. Most economists rely on their training in "neo-classical" theory to provide their paradigm for policy analysis. However, this paradigm suffers from a number of drawbacks. The first is that economists generally rely on assumptions about individual and societal behavior that may be so streamlined to accommodate mathematical models that the premises no longer reflect reality. Second, the world rarely meets the conditions established in economic theory to achieve a theoretically "optimal" outcome. Indeed, the "theory of the second best" states that implementing a change oriented towards "fixing" a single market failure (e.g., internalizing the costs of global warming) under imperfect (i.e., real world) conditions may induce behavioral changes which actually worsen the situation. Third, neo-classical theory does not easily anticipate fundamental changes in economic systems, such as those that would occur in a substantially warmer world. Estimates of behavioral responses are derived from historical relationships, relationships that may no longer prevail in a changed environment. And finally, economists tend to rely almost exclusively on the single criterion of improving overall societal wealth or "efficiency" to make their policy recommendations. As a result, economists frequently ignore other key concerns, such as income and wealth redistribution or "equity," as well as the importance of the institutional relationships that affect the costs of economic transactions.[*]

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[*]Daniel Bromley, "The Ideology of Efficiency: Searching for a Theory of Policy Analysis," *Journal of Environmental Economics and Management*, vol. 19, 1990, pp 86–107.

Economists are correct to criticize using resource conservation as a sole policy goal instead of net economic benefits.[6] They observe that no systematic studies have shown what causes the energy-conservation paradox, nor have any studies demonstrated that it is attributable to "market failures."[7] However, economists may underplay the presence of market failures. For example, credit

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[6]Sutherland, *Market Barriers, Market Failures, and Energy Issues.*

[7]Adam B. Jaffe and Robert N. Stavins, *The Energy Paradox and the Diffusion of Conservation Technology,* Working Paper, Harvard U., Cambridge, Mass., February 12, 1993.

constraints, the relationship of owners and tenants, and poorly defined property-rights are important matters that may constrain well-functioning markets in which individuals respond to costs.[8]

Despite the general evidence of some market failures, concentrating resource-use decisions in the hands of government creates substantial risks.[9] Government-based resource planning has led in the past to an over-reliance on particular resources or approaches. For example, the emergence and subsequent faltering of the nuclear power industry can be greatly attributed to the actions of the U.S. government. Other examples of misdirected government intervention in resource decisions abound and include the destruction of more than one-third of Mississippi Valley wetlands by public flood-control agencies,[10] and increased electricity rates in Northern California due to the oversubscription by third-party non-utility generators in the California public utility commission's lucrative Long-Term Interim Standard Offer contracts.

Reflecting the two dominant perspectives, policy analysts have generally proposed two different approaches for achieving energy conservation and/or emission-reduction goals. Under the first approach—the one favored mainly by economists—a tax (or emission charge) would be placed on fuels and/or emissions.[11] Proponents of this approach suggest that the charge could be based, for example, on the amount of carbon or other greenhouse gases emitted, or less directly and perhaps more consistent with the no-regrets focus on achieving general air-emission reductions, this could be based on emissions of other air pollutants.

A system of emissions charges is based on the premise that social costs will be minimized when individuals have the opportunity to make their own consumption choices in response to economic incentives and disincentives (charges) that reflect the costs of consuming resources. Essentially, this approach sets an overarching emission-reduction goal (or establishes a "cost" associated with target air emissions), but the actual decisions about how to respond to the charges are left to individuals.

The second approach—generally supported by conservationists—is based on selecting particular greenhouse gas-reduction policies, such as improved automobile fuel economy, required use of

[8]Nobel Prize-winning economist Ronald Coase stated that the profession should focus more on the existing institutional structure in assessing the actual costs of participating in markets, otherwise known as transaction costs: "Until quite recently, most economists seem to have been unaware of this relationship between the economic and legal systems except in the most general way." See R.H. Coase, "The Institutional Structure of Production," *American Economic Review*, September 1992, vol. 82, pp. 713–719.

[9]There will always be some "market failures." The critical question is what the costs of eliminating all these "failures" would be. In some instances, the costs may exceed the benefits of eliminating the "market failure."

[10]Robert N. Stavins and Adam B. Jaffe, "Unintended Impacts of Public Investment in Private Decisions: The Depletion of Forested Wetlands," *American Economic Review*, June 1990, vol. 80, pp. 337–353.

[11]Tradable or marketable emission permits generally would fall under this category. For carbon emissions in particular, the implementation of tradable permits would have to be done at the production level and would translate directly into what would effectively be a carbon charge on consumers.

alternative energy sources and transportation control measures, and implementation of a “least-cost” energy-use plan.[12] This approach relies on the ability to plan and legislate activities and behaviors to reduce fossil-fuel use, and on the ready availability of efficient, cost-effective, alternatives.

At least in theory, cost-effectiveness is the object of both approaches. Under the market-oriented approach, the presumption is that individuals (and firms) will respond to price signals by implementing the most cost-effective adjustments to their activities. Under the conservationist approach, the presumption is that planners will select the most cost-effective technological and other adjustments to production and consumption patterns. In each case, it is assumed that these choices are undertaken without regard to the distribution of reductions and costs between consumers, producers, or taxpayers.

In determining either the appropriate emissions charge level or in specifying particular emission-reduction strategies, in theory the expected emission reductions would be summed to the point where the net reductions either equal the specified targets, or the cost for the last, most-expensive additional action or technology equals the marginal (or incremental) benefit from the reduced environmental damage for that choice.

According to conservationists, proposed reductions could lead to overall societal savings *even without regard* to any carbon-emission impacts, since they deem energy conservation per se to generate net benefits. Economists are much less certain about the overall benefits of a conservation strategy. Instead, overall benefits would depend on what costs are associated with pursuing such a strategy.

III. EMISSION CHARGES: EFFECTIVE DECENTRALIZED DECISION-MAKING?

The emission-charge approach rests on the assumption that the economic system is in a roughly efficient equilibrium and that prices can adequately communicate the information needed to obtain emission reductions.[13] Using economic incentives appears on first glance to provide less-certain results than direct regulation. However, the regulatory approach requires more detailed knowledge and understanding about consumers' transportation and energy-consumption choices than the does the use of economic incentives.

The use of “command and control” strategies that *dictate*, for example, reduced automobile use would have large hidden costs by forcing allocation of resources to transportation modes that may

[12] Ralph C. Cavanagh, “Least-Cost Planning Imperatives for Electric Utilities and Their Regulators,” *Harvard Environmental Law Review*, 1986, vol. 10, pp. 299–344.

[13] While we discuss a “carbon” charge, these same observations can be applied to other types of “environmental” charges that attempt to place a value on the damages caused by various activities. For example, the prices paid for emission allowances by electric utilities under the 1990 Clean Air Act Amendments will be translated into a “sulfur dioxide” charge on electric consumers to reflect the estimated damages from acid rain.

save energy but waste other precious commodities, including people's time. The recent economic collapse of the centrally planned economies in Eastern Europe illustrates the trap inherent in attempting to dictate economic choices at a societal level rather than decentralizing decision making to individuals who weigh costs and benefits of different options as they relate to their individual circumstances, which vary widely.

A common strategy suggested by economists to reduce greenhouse gas emissions is to implement a carbon charge. Under this scheme a charge would be placed on various fuels based on the amount of carbon emitted in the form of CO_2, or its equivalent for other greenhouse gases, such as methane or NO_2. The added costs imposed by a carbon charge would give consumers an incentive to switch from technologies that emit high levels of CO_2 (e.g., coal-fired boilers), to low-emitting technologies (e.g., gas turbines or photovoltaic cells).

A targeted emission charge can be derived on several different premises. *For the charge truly to follow a "no regrets" strategy, it should be based entirely on achieving near-term, well-established environmental benefits, for example, improved air quality*. Prevention of global climate change *should not* weigh into this calculation at all because of the uncertainties regarding whether such change is occurring at all or, if so, what the impacts would be. Establishing an emission charge requires focusing on offensive chemical components (air emissions) and practices that lead to clearly identified adverse environmental effects.

At the other extreme, an emission charge can be based on pursuit of a "save-the-day" strategy. Under this approach, the charge could be based on either some postulated climate-change damages from a ton of greenhouse gases, or the required price increase to reduce greenhouse gas emissions by some prescribed amount, for example, a 20 percent reduction in CO_2 by 2005.

A third approach would be to estimate an "option value" on taking measures to reduce greenhouse gas emissions.[14] This involves determining the expected amount of damages from climate change per ton of emissions, the range and distribution of uncertainty around the estimates, and at what level of damages it would be worthwhile to respond with mitigation strategies. The value of this option could be estimated using common financial techniques, and then used to establish the level of emission charge.

Calculating and imposing a carbon charge depends on three key assumptions. First, a value for carbon emissions must be determined. Establishing the benefits, or value, of CO_2 emission reductions is difficult (if not impossible, given current information) because of the current inability to gauge the expected probability and losses, if any, associated with global warming.

Second, a carbon charge relies on the assumption that choices related to the adoption of particular technologies and consumption patterns are sufficiently responsive to price changes to change

[14] Anthony C. Fisher and W. Michael Hanemann, "Quasi-Option Value: Some Misconceptions Dispelled," *Journal of Environmental Economics and Management*, vol. 14, 1987, pp. 183–190.

emission levels substantially. A number of studies indicate a high degree of responsiveness, or "elasticity," to price changes in the long term, but much less is known about near-term responsiveness.

Finally, the estimated emission-reduction levels induced by a carbon charge would be based on calculations of baseline emissions, which may vary widely, and would generally be calculated from fuel price forecasts that can likewise diverge from actual prices. For example, oil and natural gas price forecasts have continually projected higher prices than have actually occurred over the last decade. If fuel prices remain low, baseline fuel-use forecasts will be higher, but a given carbon charge may have a greater impact because it will represent a greater proportional increase in prices.

A wide range of carbon charges has been proposed by various analysts. Figure 1 shows how much prices would increase for the three main fossil fuel sources for a carbon charge ranging between $40 and $240 per metric ton.[15] For example, a charge of $100 per ton would increase oil prices by $2.35 per million Btus (MMBtu), gas prices by $1.66 per MMBtu, and coal prices by $2.65 per MMBtu. In total, these increases would result in a doubling of fuel costs from 1989 prices.

Figure 1

[15] Emission levels for each fuel based on California Energy Commission data.

Unlike regulatory approaches, a carbon charge would raise substantial revenues for the public sector, perhaps reaching $100 billion annually or more. The disbursement of these revenues has important implications for the economy. For example, the funds could be used to reduce taxes. However, this suggestion ignores several consequences from imposing emission charges. In the face of budget deficits that will exceed $200 billion per year for the foreseeable future, revenues from carbon charges are more likely to be quickly absorbed into paying off the national debt, with minimal changes to the rest of the federal tax structure. The costs for related activities, such as travelling between locations, will increase, thus reducing the amount of taxable income; income tax revenues will decrease to a certain extent. On net, little extra revenue may be available to the government from this type of tax, especially if it is large enough to affect people's behavior and reduce greenhouse gas emissions.

In addition, the funds needed to replace personal vehicle use could act as a "carbon charge sink." For example, increased gasoline tax revenue may have to be directly transferred to transit to increase service levels.[16] The substantial adjustment costs created by higher fuel costs probably would have to be compensated to make such an option politically viable as well.

IV. MEASURING THE EFFECTIVENESS OF A GASOLINE LEVY

Based on economic principles, user fees (e.g., an emission charge, gasoline tax, road toll, or a rebate for fuel-efficiency) offer the most-efficient way to reduce vehicle emissions by encouraging people to either drive their cars less or buy more fuel-efficient vehicles. The simplest way to derive the required charge is to calculate the increase in gasoline (or vehicle operation) charges necessary to drive down emissions by some target amount.[17]

The estimated price elasticities for gasoline are usually less than one, indicating that a 1 percent increase in gasoline prices reduces aggregate consumption by less than one percent. As a result, to get a 25 percent decrease in consumption, gasoline prices must be increased by more than 25 percent. Because these price responses are based on long-term behavior, a charge could not be imposed in 1999 with the expectation that demand would promptly fall in 2000. To prevent fuel-switching by drivers, a similar charge would have to be imposed on diesel fuel.

Estimations of the direct cost of carbon charges vary substantially depending on the assumed price elasticities. Figure 2 shows the conversion of a carbon charge to a charge on crude oil and gasoline. For example, a charge of $100 per ton of carbon emissions equals a levy of $13.74 per barrel, or 39 cents per gallon. The emission reductions from a gasoline charge based on a carbon tax and three

[16] See the discussion below about the costs of programs and technologies to replace carbon-emitting activities.

[17] This is not the only type of charge or method used to increase the cost of driving. Excise taxes or registration fees on cars based on fuel economy, emissions profiles, or some other criteria; bridge or highway tolls; or other measures that reduce the cost of transit to the consumer all represent market-oriented approaches to generating changes in driving patterns.

different long-run price elasticities are shown in Figure 3. A $100 per ton charge would lead to emissions reductions of between 9 to 24 percent, with effectiveness increasing as the absolute elasticity rises from 0.3 to 0.9.

The cost per ton of reduced carbon emissions, shown in Figure 4, ranges from $20 up to $550 per ton; the cost for a $100 per ton charge would be $67 to $228, increasing as absolute elasticities fall. Because the near-term elasticities are usually closer to zero, i.e, individuals are slow to adjust their behavior due to current investment and travel patterns, the costs per ton of reduced carbon would be higher initially as people adjust both their conduct and the types of cars they drive.[18]

[18]Another study found that a carbon/gasoline tax or direct traffic management may not be effective enough to reduce traffic. The author suggests that a form of "peak load" pricing on roads and parking through time- and location-varying tolls is the preferred strategy for relieving traffic congestion. Anthony Downs, *Stuck in Traffic*, Brookings Institution, Washington, D.C., 1992.

Empirical Estimates of Gas Tax Effectiveness

Price elasticity is the currency of economic analysis. It measures the relative responsiveness of demand to changes in relative prices and equals the percentage change in quantity demanded divided by the percentage change in price. The elasticity is usually reported in absolute-value terms, i.e., a negative value is shown as a positive number. A smaller value means that a product or service is less responsive to price changes.

Price elasticity can be estimated in three general ways, either from data collected in a single location over a long period of time (time series), across locations with similar characteristics at a single point in time (cross section), or a combination of the two (pooled time series).

Substantial research was conducted on price elasticities in the early 1980s, particularly using time-series analysis, with values for short-run gasoline price elasticities falling between 0.1 and 0.3, and 0.3 to 1.0 for long-term responsiveness.[*] However, less work has been done recently, which makes estimating the effect of fuel taxes more difficult since federal fuel economy standards have had a major influence on vehicle fuel consumption. In addition, higher incomes act to increase vehicle use almost to the same extent as lower prices, an important consideration when selecting effective policies in the context of rising personal income.

A useful but simple exercise is to examine what effect pricing has on fuel use in other nations with similar incomes and cultures in a cross-sectional analysis that basically holds technology constant. On the other hand, a cross-sectional analysis returns a long-run elasticity with no time frame attached. Using world gasoline prices and vehicle-miles travelled (VMT) per capita, a price-response (elasticity) relationship was derived for 14 Organization for Economic Cooperation and Development (OECD) countries. The resulting price elasticity of VMT was 0.657, (i.e., a 10 percent increase in the gasoline price leads to a 6.6 percent decrease in miles travelled by car. (See Appendix for the model specification). The elasticity for gasoline consumption is actually higher than calculated here because auto fuel economy is elevated in nations with higher prices, thus depressing true consumer costs. It is important to note that the potential path of fuel consumption over time at various tax levels is difficult to estimate without using a complex, dynamic model.

[*] Carol A. Dahl, “Gasoline Demand Survey,” *Energy Journal*, vol. 7, 1986, pp. 67–82.

V.THE "LEAST-COST" PLANNING APPROACH: AT WHAT COST?

Prescriptive policies are based on the assumption that the existing market system is inadequate to effectively provide the incentives and essential information for individuals to make cost-effective decisions. The paradigm advocated by conservationists to choose and implement these policies has been called "least-cost planning." The methodology actually is based on an assumption of neoclassical economic theory: that the results of least-cost planning by a central authority should be equivalent to the market-driven outcome if prices fully reflect social costs.

For conservationists, too much uncertainty exists about how markets can incorporate the monetary benefits (if any) from reduced greenhouse gas emissions (as well as other man-made environmental impacts) and the results of individuals responding to price signals. Thus, their preferred alternative is to direct the implementation of particular emission-reduction and energy-conservation strategies.

In least-cost planning, the costs (or savings) per ton of emissions (weighted by a greenhouse effect or other environmental damage) are calculated for each emission-mitigation option. The options are ranked by relative cost, and planners then choose the required level of implementation to achieve the emission-reduction goals.[19]

Various strategies have been proposed as ways of achieving a "no-regrets" policy through the least-cost planning process. However, *least-cost planning proposals to date have only inadequately applied the very economic principles that their proponents claim as proof of the benefits of such planning*. While most proponents of least-cost planning calculate engineering or program costs and compare them to existing technologies and behavior in a static setting, other important economic factors are ignored. These include a failure to examine:

- how consumers and producers will react to new processes;
- how supply and demand for products and services depend on changing relative prices and income and shifts in the sharing and spread of risk;
- the path of innovation adoption; and
- the institutional relationships between individuals and organizations in society and the market.

Assuming someone will not, for example, cool their house to a greater extent if it is cheaper to do so ignores basic economic principles borne out in the empirical literature on energy conservation. Proper least-cost planning requires that the analysis be carried beyond a static single-point

[19] However, because of political, institutional and cultural factors, and the additional costs of reducing other gases, actual costs are likely to be *higher* than those estimated from simple economic or engineering models.

comparison. Issues of risk-shifting and spreading must be addressed in choosing a portfolio of policies. Central planning tends to dissipate the advantages of risk-spreading that result from having a diversity of decision makers in the marketplace.

The distribution of individual situations and outcomes also bears on the desirability of a policy choice. An assessment of these “least-cost” proposals demonstrates that the costs of reducing emissions are sensitive to several key assumptions about technology characteristics and human behavior, and as a result the actual costs can be substantially misestimated.

In the sections that follow, strategies based on command-and-control techniques are evaluated in the energy sectors that dominate greenhouse gas emissions: electricity use and transportation. The evaluation focuses on carbon-emission sequestering or mitigation measures *proposed as being low cost*. This list is not all-inclusive, but it does represent the most-discussed options.

The estimated costs for reducing carbon emissions detailed herein are described for illustrative purposes. The estimates are generally based on State of California data, since over the past two decades that state has been at the forefront in adopting advanced energy-efficiency and environmental standards and relying on alternative energy resources. The focus is on near-term options; technological innovation could lower the costs associated with many of these options, but not until after the turn of the century.

VI.PROPOSED LEAST-COST ELECTRICITY-SECTOR STRATEGIES

In general, strategies to reduce emissions in the electricity sector can be divided into two categories:

·“Demand-side” or altering consumer behavior and end-use technologies; and

·“Supply-side” or adopting new generation technologies.

The former category includes conservation to reduce overall usage and load-shifting to create higher loads when less environmentally damaging generating resources might be available. In the latter category are alternative generating facilities that generally do not rely on fossil fuels but rather on renewable resources such as water, wind, and the sun. Some new technologies, such as home-based generating systems, cut across these two groupings—the analytic principles discussed here for both types are applicable in these cases.

A.Pursuing Conservation Opportunities

The most famous advocate of conservation actions, Amory Lovins of the Rocky Mountain Institute, calls these potential energy savings “negawatts,” for *nega*tive generation of kilo*watts*. The most recent assessment of conservation potential in the United States found that electricity use in the building sector could be reduced by 45 percent, resulting in a 10 percent reduction in total carbon emissions.[20] According to this study, this conservation would result in net energy cost savings of $56 per ton of carbon emissions reductions that accompanied the reductions in energy use.

However, many conservationist analyses suffer from a lack of understanding about economics. In general, these conservation proposals are technologically oriented rather than focused on individual behavior responses. This tendency probably arises from wishing to avoid the political pain of having to tell people that reducing energy use is not a "free lunch."

In assessing the potential to reduce energy consumption through conservation, at least two different factors must be addressed. First, the feedback effects of increased efficiency on energy consumption must be estimated. For example, improved appliance efficiency will make associated energy use cheaper, thereby encouraging individuals to consume more energy. The response of increased consumption to lower costs brought on by higher efficiency is known as the "rebound" effect, a well-known response in electricity-conservation planning. As such, any estimated engineering savings must be adjusted downward to accommodate these responses.

Second, the risks associated with investing in conservation must be addressed. For example, individuals and companies generally bear the risks associated with conservation investments in new lighting or heating systems or other equipment. These risks include premature breakage, time and resources needed for learning about new equipment, the risk of not fully recovering higher upfront costs over the lifetime of the equipment, and the risk of future policy change. The risks associated with conservation investment act to discourage consumers and managers from making such investments. Mandating the acquisition of conservation technologies by government does little to spread or share these risks other than to put everyone on equally risky footing.

The only solution here is to directly subsidize these investments either through government payments or utility programs, both of which have their own drawbacks. For example, such programs can lead to "free rider" problems when individuals who would have chosen to make a conservation investment receive a subsidy anyway. A classic example occurs with air-conditioner recycling programs, where many participants who do not even turn on their units sign up to be "cycled" on hot days. Monitoring costs can be high for these programs. An additional problem is how to determine the appropriate return on investment for regulated utilities. Common regulatory practice was developed for large centralized generating plants, not for small, diffused expenditures that may or may not be producing the desired benefits.

An added complication is determining the amount of cost-effective conservation that can be undertaken, particularly for businesses. Conservation investments must match the portfolio of available investments for a business manager. That is, conservation decisions must fit not only into the financial framework that considers the costs and risks associated with the particular investment, but also must conform with the timing for installing other equipment. As a result, not all of the low-cost conservation opportunities will be exploited in an "optimal" fashion, that is, the lowest cost

[20] Rosenfeld et al., "Conserved Energy Supply Curves," pp. 45–68.

conservation measures are adopted first, up to the level where the benefits from the last measure equal its costs, holding all other production factors and costs constant. A survey of industrial water users in California found that conservation decisions followed this pattern, leading to higher conservation costs than one would find if such conservation decisions were not made in connection with other equipment installations.[21]

The amount of existing electricity conservation that can be attributed to specific government policies rather than price effects is open to question.[22] Government-mandated efficiency standards established in the 1970s and 1980s coincided with dramatic reductions in energy use over that period, but this period was also characterized by high energy prices. As energy prices fell in the late 1980s, energy consumption rose rapidly. If standards were as effective as their advocates argue, energy demand should remain relatively stable *despite* price fluctuations. Further analysis is required to determine the relative importance of the driving forces behind conservation.

While enhanced conservation investment would likely produce net benefits in the United States, these gains are unlikely to be as substantial as those estimated by various proponents. The analysis done by a team at Lawrence Berkeley Laboratory (LBL) purports to demonstrate that conservation and fuel switching can reduce U.S. CO_2 emissions from existing buildings by over 50 percent with a net present value *benefit* in terms of energy savings of $56 billion.[23]

Based on a reworking that incorporates expected consumer behavior into a recent Lawrence Berkeley Laboratory (LBL) study, an adjusted conservation supply curve for electricity, shown in Figure 5, generates 57 percent *fewer* reductions in carbon emissions from the electricity sector associated with conservation efforts, at a substantially reduced net benefit. The direct benefit in terms of reduced energy costs is about $27 per ton of reduced carbon emissions (rather than $56 per ton), or about one-half of the estimate made in the LBL study.

The LBL presentation gives a misleading estimate of potential conservation savings. A simple summing of engineering estimates ignores the critical dynamic and behavioral aspects of the analysis that are necessary to give a plausible estimate of efficiency gains. Quite simply, the LBL forecast implicitly assumes that all energy consumers have substantially the same characteristics and face the same decisions and that the stock of energy-using equipment can be transformed instantly to the latest technology.

The analysis fails to take into account the potential rebound effects of conservation. Nor does the study take into account the costs to individuals and firms from risks associated with conservation

[21]William W. Wade, Julie A. Hewitt and Matt T. Nussbaum, *Cost of Industrial Water Shortages*, California Urban Water Agencies, prepared by Spectrum Economics, Inc., San Francisco, Calif., November 1991, pp. 6–31.

[22]Jaffe and Stavins, *Unintended Impacts*.

[23]Rosenfeld et al., “Conserved Energy Supply Curves,” pp. 45–68.

investments. Finally, the LBL study does not consider how conservation matches with the portfolio of available investments for a business manager.[24]

Much of the savings identified by the LBL team are generated by a set of assumptions that violate principles key to estimating potential conservation savings. They make a series of explicit and implicit assumptions that establish an unrealistically high forecast of future energy use and of the economic attractiveness of the proposed measures.

In the first explicit assumption, they assume that the building stock stands at a level of "frozen efficiency" against which the various conservation measures should be measured. In doing this, they are trying to screen out various conservation-program efforts that will occur in the future. Unfortunately, this removes the efficiency improvements that occur simply from old appliance stock being retired and replaced with newer, more efficient technologies that exist today whether conservation is promoted or not. In addition, the frozen-efficiency assumption masks the economy-wide shift from manufacturing to service-oriented businesses that has reduced U.S. energy intensiveness per unit of output. Thus, the resulting forecasts of baseline usage are too high, and the potential savings are overestimated in this way.

With the second explicit assumption, they attempt to measure "technical" potential rather than "achievable" potential based on engineering economic analysis. In this case, they have obscured at least two important distributions by using national averages. Using a national average rate hides the fact that for some utilities, notably in the Pacific Northwest and Middle South, the costs of conserved energy (CCE) for some measures are above the utility's rate. The CCE calculated in the LBL study is based on an average usage level by a "typical" consumer. However, if a consumer does not use a particular appliance at or above estimated typical use levels, the CCE can increase substantially, making the investment uneconomic. The result is that the distribution over which the conservation measures are economic from a purely static perspective is truncated at some proportion of the total market.

Third, explicitly calculating the CCE for replacement equipment based on scrap value undervalues the existing appliance stock to consumers. The "scrap" value is based on what the appliance could be sold for in the market and includes factors such as transaction costs and tax effects. The "in-place" value measures the true economic value by calculating the physical performance depreciation, a value which will be substantially unchanged until late in the life of the product. Using an in-place value that is higher than the scrap value makes conservation investments less economic.

The first flawed implicit assumption of the LBL study is that the engineering savings from these measures will not be diminished by consumers' economic responses. These responses fall into two categories—price or "rebound" effects and increased consumption from rising income. The rebound

[24] William W. Wade, Julie A. Hewitt and Matt T. Nussbaum, *Cost of Industrial Water Shortages*, California Urban Water Agencies, prepared by Spectrum Economics, Inc., San Francisco, Calif., November 1991, pp. 6–31.

effect reflects the fact that the per unit price falls because efficiency improves, and thus consumption increases to some degree in response to the lower costs.

The effect of rising income may be even more important as we adopt more labor-saving, energy-intensive technologies as we become wealthier. If we assume that GNP will grow at 3 percent per year and the energy use-GNP elasticity is 0.8, even with conservation savings of 18 percent, total carbon emissions would grow by 6.4 percent above 1989 levels.

The second implicit assumption is that the engineering savings for each measure are simply additive to the others. In fact, one would expect an interaction between these measures that would make the savings from the whole package less than the sum of the individual strategies. To illustrate this, assume that an office building installs both a new lighting system that reduces monthly usage 200 kilowatt-hours (KWH) and a new air conditioner that reduces the load an additional 100 KWH, for an additive savings of 300 KWH per month. However, the reduced lighting may reduce the cooling load by 20 percent, and the savings from the new cooling system would then reduce load by only 80 KWH, for a total of 280 KWH or 7 percent less that the simple additive reductions.

Correcting some of these assumptions gives an adjusted conservation supply curve for electricity, shown in Figure 5, that generates 57 percent fewer reductions in carbon emissions from the electricity sector, at a substantially reduced net benefit. The adjusted supply curve uses an annual energy efficiency improvement of 9 percent by 2000 from Edison Policy Research Institute,[25] an upper bound on technological saturation of 75 percent to reflect the distribution of utility rates and consumer consumption patterns, and a combined rebound and income elasticity of 0.3, which is at the lower end of long-term elasticity estimates.[26] No corrections were made for using in-place rather than scrap value or strategy synergism because of the computational complexity. The total adjusted reduction in carbon emissions is 66 million tons, or about half of the amount estimated by LBL. The total annual benefits from energy savings are reduced from $4.2 billion to $1.8 billion.

B.Installing Alternative Energy Resources

Advocating the rapid development of renewable-resource-based generating facilities has been at the core of conservationist analysis since the 1973 oil embargo. However, the estimates of benefits and expected technological developments should be viewed skeptically. The *economic* potential for alternative, renewable-generating resources is substantially less than *technical* potential, as developing each additional megawatt becomes more expensive than the previously added megawatt. Eventually, additional development is no longer cost-effective, although some available resources technically remain. Unfortunately, these concepts are frequently confused.[27]

[25]Rosenfeld et al., "Conserved Energy Supply Curves," p. 55.

[26]Both conservation curves are modified to reflect 1989 U.S. electricity costs and CO_2 emissions, which are slightly higher than those used by LBL. (*Statistical Abstract of the United States 1991*, U.S. Bureau of the Census, Washington, D.C., 1992; Tables 972–980.)

[27]For an example of how these concepts are confused, see Chris Calwel, Allen Edwards, Cliff Gladstein and Lily

Direct investment and reliance on a new technology should be limited until it truly becomes cost-effective versus other resources. Such decisions are likely to vary among different businesses and different applications, suggesting that decentralized market decisions are appropriate for determining technology adoption.

Some of the most-promising alternative resources—natural steam power, hydropower, biomass, and solar thermal—have faced significant setbacks, particularly in the western United States. The productivity of the largest existing geothermal resource in the world, the Geysers, developed by Pacific Gas and Electric in Northern California, declined precipitously in recent years, as did the expected potential and lifetime of other Northern California steamfields.[28] Hydropower, the largest non-fossil fuel-generating resource in the world, has come under increasing scrutiny for damage to fisheries and ecosystems not only in the United States but also throughout the world. Biomass facilities are becoming less economic in the face of falling costs for natural gas and other resources such as wind power and an inability to gain any further economies of scale. In fact, many alternative-energy plants developed by independent power producers in California during the 1980s are likely to face financial difficulties by the turn-of-the-century due to scheduled downward adjustments in their energy-related payments from electric utilities.[29] Luz Engineering, the world's largest developer of solar-thermal plants, recently defaulted on many of its units and has temporarily suspended development of future plants.

Figure 6 shows the relative costs of natural gas-fired and renewable generation technologies in reducing CO_2 emissions, measured against the average 1989 incremental costs and emissions for U.S. utilities.[30] The first three technologies are various gas-fired turbines that have enhanced

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Lee, *Clearing the Air: The Dollars and Sense of Proposition 128's Atmospheric Protection Provisions,* An NRDC Special Report, Natural Resources Defense Council, San Francisco, Calif., September 19, 1990.

[28]CEC, *1992 Electricity Report*, Sacramento, CA, January 1993.

[29]Jan Hamrin and Thom Jackels, *The Development and Implications of the Interim Standard Offer 4 Contract in California,* Draft, Independent Energy Producers Assoc., Sacramento, CA, September 1, 1992. Net CO_2 emissions from biomass units could be significant. Biomass production could be a net source of greenhouse gases emissions as farm production and land-use requirements promote increased land-clearing and higher energy-use intensities for agriculture. For example, one of the key reasons for deforestation in Brazil has been land-clearing to grow sugar cane for ethanol production. A study of energy use in Californian biomass generation estimated that the amount of petroleum input per biomass output ranged from 20 to 25 Btus per 100 Btus of output.

[30]*Statistical Abstract of the United States 1991*, Tables 972–980. The costs for these resources are sensitive to the baseline assumptions about displaced generation costs and emissions, but the relative rankings stay fairly constant as the baseline changes. The shaded sections of the bar graphs represent estimated upper and lower bounds on costs for various technologies with the greatest uncertainties. While other technologies also face a range of possible outcomes, experience allows us to narrow the estimates substantially. Nevertheless, all cost estimates should be calculated for specific conditions and scenarios.

The costs per ton of reduced carbon emissions for each technology were estimated from data provided by the California efficiency and low capital costs. Geothermal flashed steam is the lowest-cost baseload alternative technology, and wind is the lowest-cost renewable overall, although its intermittent nature poses substantial operational constraints to electric utility systems. Biomass costs vary widely, from $270 to $1,400 per ton. Recent analyses show the values are more likely to be at the higher end.[31] Solar thermal facilities are high-cost, especially when gas-assistance is added to extend their operational flexibility. Photovoltaics are expected to be the most-expensive resource for general application. Phosphoric-acid fuel cells are also not expected to be cost-effective in the near future but have demonstrated significant potential. The high relative costs for maturing but most-promising technologies, such as photovoltaics and fuel cells, lend credence to a strategy that considers economic costs and delays immediate carbon-reduction measures.

VII.PROPOSED LEAST-COST TRANSPORTATION-SECTOR STRATEGIES

From a least-cost planning perspective, the most-effective methods of reducing transportation-related emissions are either encouraging people to drive less; creating technological improvements that reduce fossil fuel use; or restructuring land use so that people simply need less transport. The Clinton administration is considering a proposal to raise the corporate average fuel economy standard (CAFE) to up to 45 miles per gallon (MPG) and has justified an increase in the federal gasoline excise tax on environmental grounds.[32] These and other strategies seek to reduce polluting air emissions by increasing transportation costs, improving technology, or providing other alternative transport modes at lower costs. An assessment of their relative effectiveness is dependent on the behavioral assumptions used in the analysis.

A.Increase Automobile-Mileage-per-Gallon Standards to Over 40 miles per Gallon

Some proponents of increasing the CAFE standard argue that cost savings over a car's lifetime exceed the upfront costs of achieving better mileage, even at today's low gasoline prices.[33] However, a study using automobile industry cost estimates of improving fuel economy found that a 40 MPG standard was not cost-effective in reducing either oil consumption or CO_2 emissions compared to a range of energy taxes or adoption of alternative energy sources.[34]

Energy Commission for its *1992 Electricity Report* planning process and use a common set of forecasts to determine costs in 1997. CEC, *Technology Characterizations—Final Report*, Sacramento, CA, November 1991.

[31]Foster Associates, Inc., “Economic Impacts of Alternatives to Crop-Residue Burning,” prepared for the California Air Resources Board, San Francisco, Calif., October 1993.

[32]“Heating, driving costs could go up under Clinton,” *Sacramento Bee*, January 15, 1993.

[33]Marc Ledbetter and Marc Ross, *Supply Curves of Conserved Energy for Automobiles*, Prepared for Lawrence Berkeley Laboratory, Applied Science Division, Berkeley, Calif., March 1990.

[34]Charles Rivers Association, “CAFE Standards: How Do They Stack Up?” *CRA Review*, Prepared for the Motor

Regardless of legislatively induced higher fuel economy, improvements in engine efficiency *will not* result in one-for-one emission reductions. Drivers will take advantage of the resulting travel cost reductions to drive longer distances. This response, in turn, could lead to a further spreading of urban areas, even greater commuting distances, and increased traffic congestion. For example, the increase in miles per gallon over the last 15 years, by lowering the costs of commuting to urban job centers, may be a factor in encouraging growth in counties surrounding the Bay area and Los Angeles. This trend is reflected nationwide in the 20 percent increase in lengths of average commute trip from 1977 to 1990.[35]

Figure 7 shows the cost per gallon of saved gasoline from increasing CAFE standards based on one study promoting improved standards and incorporating various price elasticities that measure the effective reduction in driving costs.[36] The lowest cost level assumes consumers do not change their behavior as a result of improved fuel efficiency and lower automobile operating costs (i.e., they do not take advantage of reduced driving costs to drive more). Based on a price elasticity of 0.3, increasing standards to over 40 MPG is cost-effective. However, a price elasticity of 0.66 quickly drives the cost-effective standard to less than 30 MPG. Any efficiency increases are not cost-effective at higher elasticities.

An additional consideration in assessing higher CAFE standards is that fuel-economy improvements may lead to decreased passenger safety. Over the 1973 to 1989 period, higher CAFE standards resulted in a decline in automobile weight, which is the least-expensive way to improve efficiency. Two recent studies estimated that the lighter cars may have increased automobile fatalities by as much as 5 percent a year.[37] Efforts to increase car safety for fuel-efficient vehicles up to the levels enjoyed by heavier autos will only add to the costs of improving fuel economy. In addition, the accelerated phase-out of CFCs imposed by the Montreal Protocol could lead to a 6 percent loss of automobile efficiency for air conditioners, adding to the engine load and decreasing miles per gallon.[38] With air conditioners installed in over 85 percent of new cars, this can lead to significant increases in fuel consumption.[39]

Vehicles Manufacturer Association, October 1991.

[35]Stacy C. Davis and Melissa D. Morris, *Transportation Energy Data Book - Edition 12*, Prepared for Office of Transportation Technologies, U.S. DOE, by Center of Transportation Analysis, Energy Division, Oak Ridge National Laboratory, ORNL-6710, Oak Ridge, Tenn., March 1992. Table 4.9.

[36]Ledbetter and Ross, *Supply Curves of Conserved Energy*.

[37]The number of fatalities could increase by 2,200 to 3,900 higher over the lifetime of the 1989 car models according to John Graham and Robert Crandall, *Insurance Institute for Highway Safety Status Report*, September 8, 1990, vol. 25, p. 8. The estimated increase in annual deaths is 2,000 by the National Highway Safety and Traffic Administration, in "Higher Fuel Standards May Affect Auto Safety," *San Francisco Chronicle*, July 23, 1992.

[38]*Energy-Use Impacts of Chlorofluorocarbon Alternatives*, Oak Ridge National Laboratory, U.S. Department of Commerce, NTIS, DE89-008930, Oak Ridge, Tenn., February, 1989.

[39]*Statistical Abstract of the United States 1987* (Washington, D.C.: U.S. Bureau of the Census, 1987). Table 1023.

Any policy that increases the purchase cost of a new car (e.g., higher emission or efficiency standards) will slow the turnover rate in the stock of automobiles, as demonstrated over the last twenty years. The median age for cars increased by one-third between 1970 and 1990, driven in a large part by the higher new auto prices that rose by one-third between 1980 and 1990.[40] As a result, higher efficiency vehicles may not penetrate the market as quickly as policymakers have been led to believe by proponents.

B.Switch to Alternative-fueled Vehicle

Many alternative fuels produce substantially lower amounts of CO_2 than gasoline. However, most of the new technologies—natural gas, alcohol fuels, and electricity—have significant constraints relative to gasoline and only would be acceptable, at least initially, in limited roles such as fleet vehicles or commuting.[41] Consumers probably would be unwilling to invest in vehicles with higher purchase costs to replace second or third cars, which are usually older, used for lower-valued activities, and driven at least 45 percent fewer miles per year on average.[42] As such, the barriers to market penetration are significant.[43] These include:

·a lack of growth in the U.S. vehicle fuels market, driving petroleum refiners to fight to hold market share;

·an absence of a network of retail alternative fuel outlets which limits vehicle usability;

·the conservative nature of consumers' purchasing decisions;

·the small advantage for automobile manufacturers from producing a new technology which is generally well understood—that is, alternative fueled vehicle technologies are well developed, but currently they are relatively expensive; and

·performance disadvantages relative to gasoline in acceleration, range, refueling time, and storage space.

The California Air Resources Board (CARB) adopted regulations in September 1990 that are intended to promote the acceptance and diffusion of alternative-fueled vehicles in the world's single

[40]Davis and Morris, *Transportation Energy Data Book*, Tables 3.5 and 2.22.

[41]Daniel Sperling, *New Transportation Fuels: A Strategic Approach to Technological Change* (Berkeley, Calif.: University of California Press, 1988).

[42]Davis and Morris, *Transportation Energy Data Book*, Table 4.20.

[43]Sperling, *New Transportation Fuels*.

largest auto market.[44] Low-emission vehicles (LEVs) using these fuels or reformulated gasoline are required to represent 10 percent of new car sales in 1994 and increase to a 75 percent market share by 2003. The next generation ultra-low-emission vehicles are expected to be introduced in 1997, with zero-emission vehicles (ZEVs) to follow in 1998 and scheduled to achieve 10 percent market share by 2003. How the CARB intends to increase consumer demand for these vehicles if they are not cost competitive with conventional automobiles has not been specified.

Methanol and ethanol have been proposed as viable gasoline alternatives that require little change in the existing delivery and consumption infrastructure. The South Coast Air Quality Management District in Los Angeles has proposed to phase in methanol as the centerpiece of its Air Quality Management Plan, and the California Energy Commission heavily promotes methanol-fueled vehicle research. However, methanol may have only a slight or no advantage over gasoline for reducing greenhouse gases, particularly when derived from coal.[45] Ethanol may worsen air quality and currently depends on substantial production subsidies to be economically viable.[46]

One study estimated that the price of oil would have to rise above $30 per barrel (a 40 percent increase over current prices) to make alternative fuels cost competitive.[47] Figure 8 shows the range of expected costs for each type of fuel source in 1995. Methanol and compressed natural gas (CNG) are the most-promising fuels, with electricity showing a large degree of uncertainty due to the large range in possible costs.

The expected potential to reduce greenhouse gas emissions of each fuel compared to gasoline is shown in Figure 9.[48] Electric vehicles supplied only by renewable resources result in a 100 percent reduction in greenhouse gases, and electricity generated by natural gas—the most likely case in the near term in the United States—reduces emissions by 85 percent. CNG decreases emissions by 25 percent, methanol by 12 percent. Because each of these technologies is evolving, the costs per ton of

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[44]California Energy Commission, *The 1992–1993 California Energy Plan*, Sacramento, Calif., December 1991, p. 53.

[45]Evelyn F. Heidelberg, *Alternative Motor Vehicle Fuels to Improve Air Quality - Options and Implication for California*, EFH Assoc. for CEEB. Sacramento, Calif., January, 1990; Stefan Unnasch et al., *Comparing the Impacts of Different Transportation Fuels on the Greenhouse Effect,* Acurex Corp. for CEC, P500-89-001. Sacramento, Calif., April 1989.

[46]Heidelberg, *Alternative Motor Vehicle Fuels*; Sally Kane and John Reilly, *Economics of Ethanol Production in the United States*, Economic Research Service, USDA, Agricultural Economic Report No. 607, March 1989; Sally Kane and Michael LeBlanc, *Ethanol and U.S. Agriculture*, ERS, USDA, Agriculture Information Bulletin, No. 559, January 1989; *Fuel Ethanol and Agriculture: An Economic Assessment*, Office of Energy, USDA, Agricultural Economics Report No. 562, August 1986.

[47]Daniel Sperling and Mark A. DeLuchi, "Transportation Energy Futures," *Annual Review of Energy*, 1989, vol. 14, pp. 375–424.

[48]Emission factors from CEC data; Vehicle performance, CEC, *AB 234 Report: Cost & Availability of Low-Emission Motor Vehicles and Fuels*, Draft, P500-91-009, Sacramento, Calif., August 1991.

reduced carbon emissions generally are falling. Figures 10 and 11 show relative costs for methanol (M85), ethanol (unsubsidized price), CNG (dual-fuel),[49] and electricity, with the lower range for generation from renewable resources. Over the seven-year period, methanol costs are expected to fall by 50 to 90 percent, and electricity by upwards of 80 percent.

One side-effect of alternative fuels is that miles driven might actually *increase* due to the lower per-mile operating costs that natural gas and electricity enjoy over gasoline. As a result, traffic congestion and commute lengths could increase further with the introduction of these technologies unless actual road usage is priced through introduction of tolls or VMT charges.

C.Require Voluntary or Mandatory High-Occupancy Vehicle (HOV) Service

High-occupancy vehicle (HOV) service is touted as a low-cost, high-impact strategy to reduce both pollution and traffic congestion. Many regions and states are aggressively pursuing this option through legislation and regulations. To attract patrons, this option must cost less than the lone-commuter alternative, both in out-of-pocket and use-of-time costs. HOV service, while perhaps desirable, has limited impact on overall emissions in the absence of economic incentives (for example, such as congestion pricing, emissions fees, or other vehicle charges). Current car-pooling efforts have had a low market penetration despite substantial promotion, reducing gasoline consumption by less than 1 percent.[50] Also, actual effectiveness is limited for carpooling or vanpooling efforts which target commuters. For example, in the San Francisco Bay area only 34 percent of vehicle miles travelled is related to commuting.[51] Doubling the number of passengers per vehicle from 1.3 to 2.6 persons by vanpooling—if possible—would decrease emissions *solely in urban areas*. Under such a scenario, total emissions would drop by less than one percent by the year 2000.

Vanpooling has additional “hidden” costs. Because everyone in a commuter pool must follow a relatively strict schedule, arrival and departure times for workers are quite inflexible, preventing employees from undertaking unscheduled overtime and potentially cutting down on productivity late in the day as any task that might delay departure must wait until the next day. Moreover, vanpools frequently use “flextime” schedules to avoid “rush-hour” traffic, in which workers come and go during unconventional hours that may not mesh well the organization's activities. In addition, companies may have to provide vehicles or taxi fare to employees who have to return home for emergencies or other unplanned activities.

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[49]CNG costs reflect retrofitted vehicles with dual-fuel (gasoline) capability. CNG-dedicated vehicles show performance improvements of 20 percent, and lower initial costs. Sperling, “Transportation Energy Futures.”

[50]Allen Edwards, *An Analysis of Greenhouse Gas Provisions of The California Environmental Protection Act of 1990*, Preliminary Draft, Natural Resources Defense Council, July 10, 1990. See also, “Congestion Pricing for Southern California: Using Market Pricing to Reduce Congestion and Emissions” (Los Angeles: Reason Foundation, September 1992).

[51]*Market Based Solutions to the Transportation Crisis: Incentives to Clear the Air and Ease Congestion* (San Francisco, Calif.: The Bay Area Economic Forum, May, 1990), p. 4.

Actual impacts of vanpooling would depend on how they are introduced. Mandatory schemes, imposed without regard to the particular situations of individual employers and employees, could have high adjustment costs as work schedules are changed to accommodate vanpooling. On the other hand, vanpooling introduced as a voluntary response to road-pricing would allow those for whom such schemes impose the lowest costs to take advantage of vanpools.

D.Increase Land-Use Densities and Provide More Public Transit

Increasing housing and job-location densities and mass transit services in certain localities can reduce automobile use and improve air quality. However, two questions must be addressed regarding such policies. First, the cost and implications of expanded transit service and zoning requirements on automobile use must be better evaluated. Second, it is unclear whether there is sufficient political support to bring about the major land-use restructuring and shifts in transportation infrastructure to reduce travel requirements.

The public issue that requires closer examination is whether increased transit actually provides significant reductions in fuel usage. Nationwide, the fuel consumption per motorbus transit passenger is roughly equivalent to the average for passenger vehicles.[52] These averages reflect travel across all periods and for all purposes, not just during peak commuter hours, which would be the main target of transit and land-use policies. Based on an analysis of North American and Australian transit usage that incorporates population density, transit availability, fuel prices, and income, the expected cost for reducing carbon emissions in the United States by shifting to public transit is $500 to $550 per ton, a relatively expensive option.

[52]Davis and Morris, *Transportation Energy Data Book—Edition 12*, prepared for the Office of Transportation Technologies, U.S. Dept. of Energy, by Center of Transportation Analysis, Energy Division, Oak Ridge National Laboratory, ORNL-6710, Oak Ridge, Tenn., March 1992; and *Global Climate Change: Potential Impacts and Policy Recommendations*, Draft, California Energy Commission, P500-91-007, March 1991, pp. 5–12.

Estimating the Effectiveness and Costs of Transit Service

To estimate the responsiveness of gasoline consumption to increases in transit service and land-use patterns, a model was created based on data from 16 U.S., Canadian, and Australian cities that represent similar urban settings. Gasoline consumption fell at an elasticity of 0.11 with increased passenger transit miles and 0.17 with population density. Thus, a 10 percent increase in transit ridership would lead to a 1.1 percent decrease in gasoline consumption; increasing population density 10 percent decreases gasoline use 1.7 percent. Increased transit ridership occurs synergistically with higher residential and job densities, implying transit and zoning strategies must be pursued in tandem. Also significant was the influence of gasoline prices, resulting in an elasticity of 0.94, which is in the upper range for estimated long-run price elasticities. Increased transit use was driven by increased central business district (CBD) job density and lower income levels. This implies that as income levels rise over time, land-use planners will have to counter by increasing housing density and job-center concentration just to maintain existing transit use and gasoline consumption.

A separate model was estimated to calculate costs for increased transit service based on the responsiveness to changes in land-use patterns. The "production function" model assumes that the average transit trip would remain the same length after imposing emission limits, so that transit usage translated into a one-for-one increase in passengers. A 100 percent increase in transit ridership would require an increase of only 81 percent in transit service (measured in revenue-vehicle miles), which is typical for a system with increasing returns to scale.

Rail transit systems typically cost $10 million to $300 million per mile, final project costs typically exceed forecasts by 20 percent, and ridership projections are high by more than 50 percent. As an example, the Los Angeles 150-mile light rail system is expected to cost $5 billion. The old Red Line system extended over 1,100 miles in 1940. Using adjusted current cost estimates, rebuilding the Red Line would cost $44 billion. Based upon California transit costs, the estimated cost for increasing transit service only (ignoring other infrastructure changes from increased density) under 1988 conditions would be from $518 to $545 per ton of reduced carbon, generating reductions in urban gasoline consumption of one to six percent.

Transit fuel use is an important aspect of measuring emission savings. Nationwide, the fuel consumption per motorbus passenger is roughly equivalent to the average for passenger vehicles. These averages reflect travel across all periods and purposes, not just the peak commuter hours that would be the main target of land transit and land-use policies. Urban regional population density would have to increase by between 2.5 and 15 percent, and CBD job density by 5 to 30 percent, to achieve these goals.

While transit enjoys substantial public support in the United States, commuters generally believe that it is for "the other guy." A poll of Californians found that 73 percent favored increased public funding for mass transit, but less than one-quarter were willing to move from their cars into transit or other high-occupancy transportation modes.[53] In part, this reluctance reflects the "hidden" costs in transit frequently ignored by analysts. These costs include such factors as uncertain service and waiting times, the frequent need to transfer that results in increased travel time and expense, inflexibility in scheduling trips, and the intolerance of some employers of late arrivals due to failures

[53]Vlae Kershner, "Polled California Motorists Back Mass Transit—For Others," *San Francisco Chronicle*, May 15, 1991.

in transit service. Travelling to work in a single-occupant vehicle substantially avoids or reduces the risks of these costs and gives commuters control over their travel patterns.

Increasing residential density to the degree necessary to significantly reduce CO_2 emissions is likely to be infeasible. The increased-density strategy may be politically difficult for two reasons:

1. no state agencies are currently authorized to impose such land-use restrictions in the United States, and any attempt to incorporate such a strategy in an energy-management plan without such authority is improbable; and

2. taking away local zoning power would be particularly difficult in light of recent regional battles over development versus no-growth forces.

As stated in a report for two California state senate committees:

> The greatest opposition to greater densities around rail transit stations is likely to come not from the city or county or (certainly not) the development community, but from neighborhood organizations. Almost every multi-family housing project in urban California in recent years, has sparked opposition from neighborhood organizations, citing greater traffic congestions, and greater congestion in general.[54]

How mixed-use zoning, another alternative suggested for increasing transit usage, could effectively reduce emissions without increasing residential density is uncertain. While some new developments have tended towards the more desirable transit and zoning characteristics, the general trend in new housing and commercial development in the United States still runs counter to reduced automobile use.

VIII. PROPOSED REFORESTATION AND TREE PLANTING STRATEGIES

A proposed CO_2 mitigation strategy that does not fall into any end-use category involves reforestation.[55] Reforestation is seen as a strategy to reverse the conversion of timberland into agricultural and urban uses. The potential for wide-scale reforestation is unknown, as are the potential adverse side effects from increased water requirements or reductions in available agricultural land.

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[54] Michael Bernick, *The Promise of California's Rail Transit Lines in the Siting of New Housing*, A Special Report to Senate Transportation Committee and Senate Housing and Urban Affairs Committee, Arnelle and Hastie, San Francisco, Calif., April 1990, p. 112.

[55] Currently, about three and a half million acres per year are replanted in the entire United States as part of timber harvesting.

Available studies on reforestation show a wide range of cost estimates for reforestation, ranging from $29 per ton of retained carbon to $15,000 per ton.[56] For example, one study found costs as high as $4,000 per acre in California for tree planting.[57] Since an extensive reforestation effort on the required scale proposed has not been attempted before, any cost estimates are highly speculative. Costs would probably increase dramatically over current estimates as choice sites are utilized, opportunity costs for agricultural land escalated as supplies diminish, and if planting could not be accomplished through volunteer efforts.

Planting Urban Trees. Hashem Akbari and his team at the University of California's Lawrence Berkeley Laboratory (LBL) have proposed that significant energy savings could be derived from planting shade trees near houses.[58] Assuming three trees are planted per house, about 21 million new trees could be planted in California alone by the year 2000.[59] Such large-scale tree planting would result in a savings of about a quarter million tons of carbon per year or less than 1 percent of the state's emissions. Urban tree planting is one of the least-cost emission reduction options available, with costs ranging from $4 to $80 per ton.

IX. RANKING RELATIVE COSTS FOR EMISSION REDUCTION STRATEGIES

The analysis presented here represents only a first step in the necessary inquiry—at least three additional areas should be explored in future analyses to produce a more comprehensive assessment. First, the costs for each strategy should be calculated over time (i.e., dynamically), including estimates of changing economic responsiveness to price and income effects. Second, the robustness of relative cost estimates should be tested by varying important factors, e.g., the discount rate, to

[56]The Independent Energy Producers produced a survey of reforestation cost estimates for the CEC's *1990 Electricity Report* proceedings. Hashem Akbari et al., from LBL, has estimated costs at $28.60 per ton of reduced carbon; Krause and Koomey, also from LBL, calculated costs at $31.50 per ton; Nahigian of JBS Engineering calculated a range of $37 to $117 per ton using U.S. Forest Service planting costs; Chernick and Caverhill calculated costs from $29 to $15,000 per ton from a number of sources, and determined that a range of $44 to $220 per ton was most appropriate in the most definitive study. Ralph Cavanagh of the NRDC cites a study by Pacific Power and Light that calculates the cost of reforestation at $132 per ton. As Chernick and Caverhill observed, all of these estimates account for *gross* CO_2 uptake, ignoring the net loss of the plant biomass that previously existed where the trees are planted.

[57]California agricultural land sells for more than twice the national average (*California Almanac*, op.cit.).

[58]Hashem Akbari, Art Rosenfeld, and H. Taha. "Recent Developments in Heat Island Studies: Technical and Policy," *Controlling Summer Heat Islands*. Proceedings of the Workshop on Saving Energy and Reducing Atmospheric Pollution by Controlling Summer Heat Islands. LBL Berkeley, Calif., 1989. The Sacramento Municipal Utility District is starting a tree planting program with a goal of 500,000 homes, and estimates the cost per tree to range from $30 to $60, with a 90 percent survival rate. The City of San Francisco estimates planting a tree costs $100 to $300. The LBL study apparently uses a cost of $3 per tree.

[59]Based on LBL savings estimates of 80 kilowatt-hours per tree, by adding the Independent Energy Producers' estimates of CO_2 uptake rates for trees, and assuming that 60 percent of California households would plant these trees (the home ownership rate).

reflect various values. And third, achievement of multiple goals, particularly related to environmental quality, should be measured and weighed against the ensuing costs. For example, given the significant difficulty of measuring the economic benefits of reductions in polluting air emissions, these benefits are excluded from this analysis. All analyses described here measure costs against only one dimension (CO_2 reductions) and ignore other dimensions, such as ambient air quality, for example.

With these caveats, Figure 12 compares the relative costs of the technologies and strategies discussed here for the 1995–1997 time horizon. On average, conservation investments show net benefits, although the incremental additions have significant costs. For electricity generation, natural gas and wind technologies appear to be relatively cost-effective. In transportation, the relative costs depend on consumers' responsiveness to price changes and the operative time horizon. As driving becomes more sensitive to fuel prices, gasoline taxes become a more cost-effective policy relative to fuel economy standards. Electric cars may be cost-competitive by 2000. Transit, combined with changes in land-use configurations, appears to be a costly option when measured as a carbon-emission reduction strategy. The different tree-planting strategies are economically attractive compared to the technological and programmatic alternatives.

Looking across strategies, few actually generate net savings based on a static economic analysis. The gas tax creates reductions at a lower cost because it induces a two-dimensional response—both a reduction in fuel use through curtailed travel and adoption of more-efficient technologies. The other options generally focus on only one type of response.

X.DO THE ENDS JUSTIFY THE MEANS?

Fundamentally, discussions about global-warming policies reflect two divergent perspectives about the role of government in a policy setting. Those relying on economic theory argue that economic incentive policies (emission charges, for example) leave government planning to the task of establishing the emission-mitigation goals, while generally leaving planning decisions to individuals in the economy. Many economic theorists also argue that in the context of fundamental uncertainties about whether greenhouse gases pose an actual threat, *any policy* should be based on reducing near-term, well-established environmental benefits rather than focusing directly on achieving reductions in greenhouse gas emissions.

For those with a conservationist perspective, achieving the mitigation goals with a high degree of certainty is imperative. Thus, they argue, the government must become directly involved in choosing the appropriate behavioral and technology responses.

The analyses of both the carbon charges and the specific measures that might be included in a least-cost plan demonstrate the uncertainty of any policy option aimed directly at reducing greenhouse gas emissions. The social sciences have not given us enough information to predict human behavior with the accuracy required to choose a least-cost plan nor to predict how individuals will respond to price signals that are intended to create fundamental changes in how we go about our daily business.

Moreover, the significant debate about whether greenhouse gas emissions even pose any actual threat at all persists. Thus, policy makers should recognize the limitations and risks inherent in pursuing any global-warming policy.

In addition, policy-makers need to recognize that global warming is just that—a potential *global* problem. Thus, unilateral local, regional, or even national efforts are likely to be ineffective in significantly lowering greenhouse gas emissions. Policy proposals at the national, state, and local levels may even have detrimental, though unintended, effects. The fastest-growing source of greenhouse gases is from developing countries who are unable to exploit existing technology developed to a large degree by progressive California industries and innovators. Deliberately reducing CO_2 emissions in a state (or nation) with relatively high energy efficiency and a rapidly diminishing share of world emissions, (e.g., California), would have little or no effect on aggregate worldwide greenhouse gas releases. Instead of spending billions of dollars for minimal improvements in world emission levels, investment in enhancing the energy efficiency of developing countries would be a much more effective solution for meeting any reduction goals that policy makers might pursue.

In addition to the above caveats, the United States should be cautious about proposing to emulate the transportation and energy policies of other nations. Transportation and urban planners tend to compare the United States with Europe and japan, because these countries have lower automobile use while enjoying a similar standard of living. Yet two key factors distinguish the United States from these other countries. The first is spatial: the United States has a much lower population density due to its immense size and dispersed cities. Establishing public transportation and land-intensive uses simply are not generally economic in the United States. The second is historical: most settlement in the United States occurred after the development of mechanical transportation modes, while Europe and Japan developed much of their urban settlement patterns before the nineteenth century. The United States also saw an acceleration in income levels in the early twentieth century relative to the rest of the world that led to a higher level of consumption just as automobiles became established. Both Europe and Japan had their development interrupted by world wars that forced them to rebuild their infrastructure for a population that was relatively poor at the time. The closing of the income gap with the United States has been a relatively recent phenomenon. The different circumstances—in terms of land-use patterns, resource availability, and so on—suggest that appeals to European (or Japanese) models are inappropriate.

Finally, if global climate change does not materialize, pursuing all-out reduction efforts for little or no gain could cripple the economic development of future generations. *Both market-oriented and command-and-control measures based on a single-purpose strategy of reducing greenhouse-gas emissions are likely to be costly, since both types of measures would introduce significant changes in current energy-consumption patterns without any certitude that the targeted emissions are currently having any adverse impacts.*

On the other hand, if the predicted warming does materialize, the ensuing ecological and societal problems could overwhelm our systems of governance and commerce. Thus, a no-regrets strategy directed at improving energy efficiency and reducing other emissions with well-understood adverse impacts (while bringing about reductions in greenhouse-gas emissions as a side effect) may be warranted.

However, even within this broad no-regrets approach, specific policies will have significant differences in cost. Market-oriented strategies based on conveying market price signals about resource use, energy consumption, and known air emission impacts promote decentralized decision-making in which individuals make their own adjustments to price information. Command-and-control measures, by contrast, essentially centralize decision-making about technology and consumption behavior. This forecloses opportunities for individuals and firms to find the most-efficient responses to changing cost structures. This, in turn, is likely to translate into high costs.

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APPENDIX: MODEL EQUATIONS

OECD Vehicle Miles Traveled: Gasoline Price Elasticity

This model estimates the cross-sectional price elasticity using a Cobb-Douglas demand function. The formulation assumes that the unobserved excluded variables are uncorrelated with the price of gasoline—an assumption that requires closer examination in a full-scale analysis.

$$\text{Log}(\mathit{VMT/Capita}) = \underset{(44.9)}{8.54} - \underset{(3.08)}{0.657}\,\text{Log}(\mathit{Gasoline\$/Gal}) + e$$

1

$$DF = 12 \quad R^2 = 0.442$$

VMT/Capita = Vehicle miles travelled per person in each country (1987)
Gasoline$/Gal. = Gasoline pump price per gallon (1987)

North American and Australian Cities Gasoline Use: Transit & Density Demand

This model estimates the cross-sectional demand for gasoline based on the estimated demand for transit services, the population density and the price of gas. The demand for transit service was estimated on the central business district's job density and the income of each metropolitan area. Both formulations use a Cobb-Douglas demand function.

2

Gas = Gasoline consumption per capita (1980)
TransitPass-Mi = Transit passenger-miles per capita (1980)
Pop./Acre = Population density (1980)
Gas Price = Gasoline pump price per gallon (1980)

$$\text{Log}(\mathit{TransitPass - Mi}) = \underset{(3.42)}{35.04} + \underset{(5.28)}{1.246}\,\text{Log}(\mathit{CBDDen.}) - \underset{(3.33)}{3.994}\,\text{Log}(\mathit{Income}) + e$$

$$13\ D.F \quad R^2 = 0.697$$ 3

$$\mathit{System}\ R^2 = 0.977 \quad \chi^2 = 60.133\ \ 5\ D.F.$$

CBDDen. = Central business district job density (1980)
Income = Per capita income (1980)

U.S. Transit Costs: Service Costs

This model estimates a Cobb-Douglas production function for California transit systems. These parameters were applied to U.S. transit costs to approximate the cost of increased transit service.

$$\mathrm{Log}(Cost/Pass.) = 1.93 - \underset{(4.82)}{0.342}\,\mathrm{Log}(Pass./Capita) + e$$

$$5\ D.F. \quad R^2 = 0.82$$

4

$$\mathrm{Log}(RVM/Pass.) = -0.04 - \underset{(2.36)}{0.298}\,\mathrm{Log}(Pass./Capita) + e$$

$$5\ D.F. \quad R^2 = 0.53$$

Cost/Pass. = Operating costs per passenger
Pass./Capita = Transit passengers per capita within transit service area
RVM/Pass. = Revenue vehicle-mile per passenger