The Scope for Energy Efficiency Improvements in Transportation

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The transportation sector of the modern economy is not the primary contributor to carbon dioxide (CO_2) emissions, but decreases in the energy used by the sector can play an important role in their reduction.[1] These changes, which are necessary, but not sufficient to address the impacts of climate change caused by CO_2, will be realized by improvements in the energy efficiency of transportation. The scope for such improvements is sizeable and multifaceted: technological advancements and behavioral adjustments both offer options for achieving impressive reductions in energy use and emissions. But if these improvements in energy efficiency are going to be meaningful and cost-effective, then thorough policy making that addresses transport technology, behavior and perception is also required.

That a reduction in CO_2 emissions in the transport sector is a relative "drop in the bucket" in terms of the total emissions sufficient to ensure effective climate change mitigation is not an argument for inaction. Indeed, Britain's Royal Commission on Environmental Pollution (1995) believes that it is necessary because there is a "large potential for increased efficiency in the use of energy by transport at relatively low cost" and because it will positively impact on the other environmentally undesirable effects of transportation. Moreover, the predicted increases in transportation emissions argue against inaction (NYSEPB, 2001; El-Fadel and Bou-zeid, 1999).[2]

The transport sector's contribution to CO_2 emissions is certainly substantial enough to warrant serious reductions in emissions: in both developed and developing countries, its CO_2 emissions constitute 20 to 25% of total CO_2 emissions (El-Fadel and Bou-zeid, 1999; RCEP, 1995; Hughes, 1993). In the United States, for example, CO_2 emissions by transportation increased from 20.6% to 24.7% between 1970 and 1991; this trend is expected to continue into the twenty-first century, especially in terms of passenger transport in the face of rising car ownership and personal mobility (NYSEPB, 2001; Lakshmanan and Han, 1997; Hughes, 1993).

Lakshmanan and Han (1997) argue, however, that these increases were moderated by "improvements in transportation energy efficiency." Therefore, even if an increased focus on these improvements in energy efficiency (both technological and behavioral)[3] cannot fully counterbalance growth in demand for transportation, it is warranted and will be meaningful.

Because of its scientific nature, the scope for technological energy efficiency improvements in transportation is more easily quantifiable and, thus, better studied and often more politically acceptable. The car industry certainly places more emphasis on this approach: it would rather adapt its fleet technologically than see behavioral modifications reduce the demand for vehicles (Hughes, 1993). There are numerous technological advancements that are being researched and developed – most of them focus on the operational (running of the vehicle) aspects of transportation efficiency.[4] A brief review of these potential options will reveal the broad scope for improvement in the energy efficiency of the transport sector.

There are two categories of technological improvements that will be addressed in this paper. The first involves passenger vehicles (and engines and fuels);[5] the second involves computer-controlled Intelligent Transportation Systems (ITS). The scope for increased energy efficiency through technological improvement of the passenger vehicle is large. Studies indicate that less than 20% of a car's energy consumption is used in providing motion – the rest is lost as waste energy (DeCicco and Delucci, 1999; Hughes, 1993). Some of this limitation stems from thermodynamic constraints, but most of it is caused by vehicle and engine inefficiencies.

In particular, the physical condition of a car can affect its fuel efficiency/economy. For example, older cars (with worn components), under inflated tires, poor quality engine oils, misaligned wheels and poorly adjusted brakes all translate into increased fuel consumption (Hughes, 1993). Actions taken to fix these problems, including vehicle repair and road maintenance, go a long way toward reducing emissions (NYSEPB, 2001). Another issue that impacts on fuel economy is vehicle and engine design. Hughes (1993) presents compelling data on the potential for increased energy efficiency within this sphere (see Appendix 1).[6] Directly related to the issues of condition and design is the fact that malfunctioning exhaust and emissions controls "comprise the largest [50%] and least understood source of [CO, HC, NO_x] emissions" (DeCicco and Delucci, 1999).[7] This is another area in which fuel economy can be improved.

Some of the best research into, and potential for, technological improvements is in the area of "alternative fuels." As with renewable energies (biomass, solar, wind), however, alternative fuel vehicles (AFVs) often require more energy to generate their fuel than is saved by their consumption efficiency. An excellent example is the electric car. Although its conversion of energy to traction is more efficient than that of an internal combustion engine, the benefit is lost as a result of the energy wasted in generating the electricity (DeCicco and Delucci, 1999). Therefore, its true value in reducing emissions can only be realized if the electricity is provided by non-fossil sources or natural gas (Hughes, 1993). Similarly, the ability of cars powered by natural gas, alcohol-based and hydrogen fuels to reduce CO_2 emissions depends critically on the means used to generate the fuel (Maddison, *et al.*, 1996; Hughes, 1993).

Even with non-fossil generation, many of these alternative fuels pose possible problems in terms of reducing emissions. For instance, the potential 35% reductions of CO_2 emissions by vehicles powered by natural gas (compared to gasoline) are likely to be offset by the release of methane (CH_4), a key element of natural gas and a greenhouse gas that can escape by way of leakages from plants (Hughes, 1993). This is especially important because CH_4 has a global warming potential (GWP) twenty-five times that of CO_2 (El-Fadel and Bou-zeid, 1999).[8]

Other sources indicate, however, that gains in energy efficiency with AFVs are possible, given a certain economic cost. Electric vehicles, it is argued, offer an 82% energy efficiency improvement at a 27% price increase (DeCicco and Delucci, 1999). Toyota's hybrid electric-gasoline Prius car produces CO_2 emissions that are half those of a conventional car and costs 10 to 15% more (Albrecht, 2000). Impressive greenhouse gas emissions reductions can also be achieved, albeit at a "major" economic cost, for hydrogen- and ethanol-powered vehicles (RCEP, 1995; see Appendix 2). Like the potential impacts of climate change, this cost is higher than the benefits for a period of time. It is argued that the costs (US$35 billion cumulative) of the transition to AFVs will initially outweigh the benefits (US$80 billion cumulative), which will be realized in the years to come (DeCicco and Delucci, 1999).

Similarly, the implementation of the technology will be marked by a significant time lag. In their seminal work on climate change, Wigley, Richels, and Edmonds (1996) make a strong case for a delay in the full implementation of more efficient technologies because of the positive marginal productivity of capital, delays in changeover of the capital stock and future technical progress. This argument can be applied to the improvement of energy efficiency in the transport sector: "Both improvements in energy efficiency and renewable-fuels use are constrained by time lags associated with their investment requirements" (DeCicco and Delucci, 1999).

The second category of potential technological improvement in energy efficiency centers on computer-based Intelligent Transportation Systems (ITS). In this case, information technology is used primarily to improve the flow of traffic, thus reducing energy usage and emissions that are caused by congestion (RCEP, 1995). ITS technology became a reality in the United States with the enactment of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 and it is gaining increased attention around the world. ITS is especially noted for its remarkable performance during the operation of functions such as synchronizing traffic signals, collecting highway tolls (for example, New York State's expanding E-Z Pass automated toll system) and generating and disseminating traffic information to drivers and traffic managers (NYSEPB, 2001; Horan, *et al*., 1999).[9]

The fact that ITS has been conceived and designed by transportation engineers raises an important question that impacts on its ability to improve the energy efficiency of the transport sector: will ITS focus on moving traffic as quickly as possible (irrespective of the environmental costs or benefits) or will it promote sustainability based on reduced congestion, energy usage and emissions (Horan, *et al*., 1999)? There is evidence that both patterns will emerge. Only 1.2% of the federal ITS budget is allocated to projects in which the primary motive is environmental concerns, while in Minnesota, the Department of Transportation has initiated a Sustainable Transportation Initiative (STI) to implement sustainable ITS (Horan, *et al*., 1999).

There has been less research into the absolute and relative emissions reductions stemming from ITS, but there is compelling evidence that it can make a significant contribution to sustainability. Advanced traffic management (for example, traffic signal coordination), traveler information (pre-trip and en-route) and advanced vehicle identification (for example, congestion-sensitive road tolls) all reduce energy usage and congestion-related emissions "significantly" (Horan, *et al*., 1999). These technologies serve as precursors to automated highway systems that may come to dominate the transport sector in the future – upon implementation, energy and emissions benefits will increase as a result of more consistent speeds, fewer stops and less time idling (NYSEPB, 2001). But this futuristic ideal raises questions about the real scope of technology improvements in the transport sector. For example, are current and future technologies realistic and efficient enough to offer meaningful and cost-effective improvements in energy efficiency?

There is an overwhelming consensus in the literature that technologies are promising, but that they will not be enough to ensure meaningful and cost-effective improvements in energy efficiency. Despite the fact that technological improvements have moderated the rate of increase of greenhouse gas emissions, they "will not be able to offset impacts due to growth in future travel demand" (El-Fadel and Bou-zeid, 1999). This echoes Hughes (1993) argument that

> …the vision of clean, environment-friendly cars is based more on wishful thinking than on hard reality, and there is a danger that an over-emphasis on technological solutions will overshadow the need for more fundamental changes in the nature of travel.

Hughes (1993) estimates that taken together, technological changes and policies aimed at moderating the demand for travel could reduce CO_2 emissions by 20 to 25%.[10] Therefore, it is necessary to address the scope for behavioral improvements in energy efficiencies in the transportation sector.

Behavioral improvements in energy efficiency are aimed at a shift toward less CO_2-intensive modes of transport and at reducing the absolute growth of all travel modes. This paper will address both market-based and regulatory approaches to behavioral improvements aimed at reducing the demand for travel, or the "need for mobility" (Robertson, 1999). It will also be useful to examine the psychological aspects (perception) of transportation decisions because they have an impact on the success of technological and behavioral improvements within the sector.

Similarly, it is necessary to analyze the effectiveness of, and need for, supportive policies aimed at changing both the technology of transportation and how the system is used. DeCicco and Delucci (1999) present a useful summary of the need for this multifaceted approach: in attempting to answer the question "Is technology enough?" it was agreed that "yes, technological solutions can be found, but no, they may not come to fruition without new programs and policies." In addition, "the feasibility of technologies, programs, and policies rests greatly on non-technological issues of perception and behavior" (DeCicco and Delucci, 1999).[11]

One type of behavioral improvement in energy efficiency involves the way in which a car is driven because it directly effects fuel consumption. For example, the speed of travel has a non-linear effect on the amount of fuel consumed: from 0 to 70 kilometers per hour, the consumption of fuel decreases; above that, fuel consumption increases (Hughes, 1993; RCEP, 1995). Because higher speeds (above 70 km/hr) translate into higher fuel consumption and higher emissions, policies that limit speed, and enforce these limits, will have a positive impact on the energy efficiency of transport. Similarly, shorter trips and trips taken in winter are less fuel efficient (Hughes, 1993; Button, 1998). Therefore, policies taken to limit this type of activity can have benefits for energy efficiency in transportation.

Recker and Parimi (1999) also argue that there is the potential for emissions reductions from changes in traveler behavior. Their study indicates that a shift toward "optimal activity scheduling/travel behavior (including ridesharing)" would result in a 30% decrease in CO emissions (Recker and Parimi, 1999). This is important, considering their claim that modernization of the current fleet of cars alone would lead to an equivalent reduction (Recker and Parimi, 1999). Therefore, policies that encourage efficient trip chaining and scheduling of activities could lead to "significant" reductions in vehicle emissions.

An analysis of behavioral considerations must also examine the costs and benefits of road pricing, a policy tool that operates under the notion that when demand for roads is high, prices should be high to deter excessive use (Button and Verhoef, 1998).[12] It is argued that because CO_2 emissions are proportional to fossil fuel use, a fuel tax is the most efficient way to deal with the problem: indeed, the "global warming problem is hardly an argument for road pricing, even though it is one of the most serious problems facing the transport sector today" (Button and Verhoef., 1998). However, it seems clear that road pricing is mandated. It is used to relieve traffic congestion and because congestion is a major source of excess fuel consumption (and, thus, emissions) road pricing will help to reduce greenhouse gas emissions. Like the ISTEA legislation, road pricing was originally designed to reduce traffic congestion, but today, it has the potential to address issues of sustainability, such as energy use and CO_2 emissions. That is, increasing commuting costs has the distinct "potential to increase commuting efficiency" and raise awareness of the impacts of vehicle emissions (Scott, *et al*., 1997).

Policy decisions that are taken to curb growing demand in the transport sector can also be well informed by an understanding of the psychological aspects of traveler behavior. A recurrent theme in the literature on traveler perception and behavior is the idea that car ownership and use encourages travel by car. Hong Kong is an excellent example: Cullinane and Cullinane (2003) present a case study of this city characterized by low car ownership and use and an impressive public transport system. First, they show that controlling car use by improving congestion is counter-productive because it simply encourages more individual travel. Instead, congestion improvements should be aimed at public transport service (for example, dedicated bus lanes). Second, they show that in order to deter car use (and emissions), car ownership must be controlled because "once a car has been purchased, people become dependent on it for virtually all journey purposes" (Cullinane and Cullinane, 2003).

What benefits of car ownership and use make it more desirable than public transport? Hiscock, *et al*. (2002) argue that attachment to cars can be explained by the protection, autonomy and prestige that they bestow upon individual travelers. Therefore, any policy aimed at reducing demand and inefficient behaviour must provide or substitute for these benefits. Although some argue that clustered urban spaces would help public transportation to provide these benefits, Hiscock, *et al*. (2002) believe that public transport must focus on providing its customers with choice, convenience, reliability and predictability. These efforts, combined with “targeting” (marketing), would make public transport more attractive (by providing equivalent benefits) and the transport sector more energy efficient (Hiscock, *et al*. 2002). The success of this approach is evident in New York State, which has the most energy efficient transportation sector and the lowest fuel consumption per capita in the nation because its reliable and accessible transit system encourages high levels of public transportation (NYSEPB, 2001).

Several policy options suited for improving energy efficiency in the transport sector have already been addressed, especially as they relate to travel behavior, but there are many more opportunities for local, regional and national legislative initiatives aimed at promoting technological improvements. A good example that already exists is the regulation of fuel economy. In the United States, Corporate Average Fuel Economy (CAFE) standards (in this case, miles per gallon) were introduced under the Energy Conservation Act of 1975 (NYSEPB, 2001). Continued enforcement and increases of these standards, which have been very effective to date, will ensure a more energy efficient transport system (NYSEPB, 2001).

Similarly, the continued existence and improvement of federal surface transportation, (for example, the ISTEA) will provide improvements in energy efficiency. The ISTEA can serve as an excellent template for policy making because it has promoted both transportation efficiency and sustainability (energy efficiency) (NYSEPB, 2001). It also gives “teeth” to previously ineffective surface transportation and to the “directive that transportation investments be environmentally sensitive” (Horan, *et al.,* 1999).

Malfunctioning vehicle controls and the contribution of car manufacturing to emissions (addressed above) also provide opportunities for policy to help improve energy efficiency. For example, inspection and maintenance (I/M) and on-board diagnostic (OBD) programs can be developed and implemented to optimize the fuel economy of cars (El-Fadel and Bou-zeid, 1999; DeCicco and Delucci, 1999). Furthermore, the introduction of tradable emissions permits into the car manufacturing industry can lead to “significant reductions of CO_2 emissions” – on the order of 25 to 38% – depending on the value of the certificate (Albrecht, 2000).

Financial policy tools can also promote behavioral improvements in energy efficiency. For example, carbon taxes and tax rebates would encourage the purchase of more fuel efficient cars (NYSEPB, 2001; Maddison, *et al*., 1999; El-Fadel and Bou-zeid, 1999; Button and Verhoef, 1998). Likewise, tax incentives that moved urban planning in the direction of greater urban density and settlement size, could be levied, thus discouraging travel demand while increasing the potential for public transit opportunities (Hughes, 1993; El-Fadel and Bou-zeid, 1999). This would be preferable, from an efficiency standpoint, to increasing the capacity through additional roads, which Nagurney (2000) argues has the paradoxical effect of increasing emissions.

It is evident, therefore, that the scope for improvements in the energy efficiency of transportation is sizeable and multifaceted. Mostly supply-side (technological) and demand-side (behavioral) modifications, promoted through deliberate policy, can together lead to meaningful and cost-effective reductions in energy use and CO_2 emissions. The reductions that are achieved will constitute significant contributions to efforts that address the impacts of climate change, but they will only represent one part of the massive reductions that are necessary. This is not an excuse for inaction. Instead, it can serve as a relatively painless point of departure for efforts to reduce emissions.

Appendix 1. Design technologies available for improving car fuel economy*

System	Technology	Fuel Saving (%)
Engine design	Precision cooling, reduced engine friction, reduced pumping losses	Up to 6
Power plant	Four valves per cylinder, four stroke Direct injection two stroke Diesel engine Electronic engine management	5 to 15 Up to 10 20 to 30 5 to 20
Vehicle/transmission design	Automated manual Continuously variable transmission Weight reductions Aerodynamic improvements Tire, lubricant, accessory improvements	10 to 15 10 to 15 15 to 20 5 to 10 5 to 10

* After Hughes (1993), Table 6.1, page 81.

Appendix 2. Alternative fuels – emissions reductions and costs*

Fuel	Net percentage change in greenhouse gas emissions (cradle to grave)	Cost disadvantage
Natural gas/methane	-21 to +5	Slight
Liquid petroleum gas	-30 to –10	Slight
Hydrogen (made with solar or nuclear power)	-70 to –10	Major
Ethanol	-75 to –40 (if from wood) -20 to +30 (if from corn, sugar, etc.)	Major
Rape methyl ester	not known	Significant
Methanol	+30 to +70 (if from coal) -15 to +5 (if from natural gas)	Significant

* After RCEP (1995), Table 8.4, page 126.

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[1] It is important to note from the outset that reductions in total energy use directly relate to reductions in CO_2 emissions. "Unlike other greenhouse gases (e.g. N_2O) whose emissions are not only determined by the amount of energy used but also by energy use technologies and emission controls, CO_2 emissions have a stable physical relationship to energy use" (Lakshmanan and Han, 1997).

[2] For example, the New York State Energy Planning Board (2001) estimated that the daily vehicle miles traveled (DVMT) in New York would increase by 30% in the next two decades.

[3] In the current debate about the trade-off between the annual percentage decline in energy intensity and the amount of carbon-free energy necessary to reduce emissions of greenhouse gases there are two dominant viewpoints. On the one hand, Hoffert, *et al*. (1998) argue that a relatively lower decline in energy intensity indicates the importance of technological change. On the other hand, the Intergovernmental Panel on Climate Change Working Group III (2001) argues that a relatively higher decline in energy intensity indicates the importance of behavioral change. In contrast, however, it is important that the policy implications of improving the energy efficiency of the transport sector *not* be understood as mutually exclusive.

[4] Most analyses consider the "operational" aspects of running a vehicle, which covers the emissions released during its use. This is to be distinguished from the "primary energy" required by transport (which takes into account the energy consumed and emissions released while obtaining, processing and delivering the fuel) and from emissions

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released during the production of the car. The latter typically releases 1-2 tons CO_2, while the emissions released during a car's lifetime number 37.5 tons CO_2 (Hughes, 1993; Albrecht, 2000).

[5] Hughes (1993) notes the special position of privately-owned cars: unlike buses, railroads and airplanes, which typically employ the most efficient vehicles in order to reduce operating costs, the fuel economy of cars is worse because buyers rate comfort, performance and size more highly than miles per gallon.

[6] Hughes (1993) does spend some time addressing actual "alternative heat engines" (for example, Stirling, gas turbine and Rankine), but finds their potential contribution to reduced CO_2 emissions to be extremely limited.

[7] These gases, especially CO, play important roles in the atmosphere. CO, which is a by-product of incomplete combustion in an internal combustion engine, is largely converted into CO_2 upon entering the atmosphere (DeCicco and Delucci, 1999; Lakshmanan and Han, 1997).

[8] The Global Warming Potential (GWP) of a gas is defined as the "time integrated radiative forcing resulting from the instantaneous release of a unit mass of the gas in today's atmosphere expressed relative to a reference gas" (in this case CO_2) (El-Fadel and Bou-zeid, 1999).

[9] More specifically, ITS can be organized into five categories: advanced traffic management systems (ATMS), advanced traveler information systems (ATIS), advanced vehicle identification (AVI), commercial vehicle operations (CVO) and advanced vehicle control systems (AVCS) (Horan, *et al.*, 1999).

[10] The New York State Energy Planning Board (2001) has taken this idea into account: their Draft Energy Plan states that energy efficiency can be enhanced by reducing vehicle miles traveled, increasing fuel economy and reducing demand and vehicle delays.

[11] It should be noted that their argument for the 'adequacy of technology' is not a case for inaction; rather it is a suggestion that technology can provide answers if fully pursued (DeCicco and Delucci, 1999).

[12] Arthur Pigou first introduced this concept in the 1920s. The main problems associated with the approach include the development of technically efficient charging mechanisms and gaining political acceptance as a legitimate policy instrument (Button and Verhoef, 1998).

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