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Sustainable Transport Technology: Framework for Action

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SUSTAINABLE TRANSPORT TECHNOLOGY:

FRAMEWORK FOR ACTION

by

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DELCAN

September 1997

This report reflects the views of the authors and not necessarily those of the Transportation Development Centre.

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16. Abstract

This report identifies and categorizes technologies that potentially can support sustainable transport; assesses and screens these technologies for further detailed evaluation by Transport Canada; comments on the applicability of the screened technologies and the federal government's possible role in supporting them; and develops practical criteria for evaluation of their potential.

The sub-categories that offered the broadest potential to reduce adverse effects are: reduced resource consumption, advanced vehicle developments, alternative fuel powered vehicles, advanced engine developments, and traffic management. These areas should be the focus of a future assessment.

The report also recommends the development of an action plan detailing policy directions and possible roles for Transport Canada and other federal departments and agencies. In addition, it establishes the mechanisms for broad, cooperative efforts with other governments, other public agencies, the private sector, and academic and research institutions.

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16. Résumé

Le présent rapport fait l'inventaire et une catégorisation des technologies pouvant s'inscrire dans une stratégie de transport durable; évalue ces technologies et sélectionne celles qu'il y a lieu de soumettre à une évaluation approfondie par Transports Canada; examine l'applicabilité des technologies sélectionnées et le rôle possible du gouvernement fédéral dans l'avancement de ces technologies; et expose des critères pratiques pour l'évaluation du potentiel des technologies retenues.

Les technologies offrant le meilleur potentiel d'atténuation des effets néfastes des transports sur l'environnement sont regroupées dans les sous-catégories suivantes : consommation réduite de ressources, innovations touchant les véhicules, véhicules utilisant des carburants de substitution, innovations touchant les moteurs, et régulation du trafic. Ces domaines devraient faire l'objet d'une évaluation future.

Le rapport recommande enfin l'élaboration d'un plan d'action assorti d'orientations politiques, et définit les rôles possibles de Transports Canada et des autres ministères et organismes fédéraux. Il propose finalement des mécanismes propres à susciter la coopération entre les divers paliers de gouvernement, les organismes publics, le secteur privé, ainsi que les établissements d'enseignement et de recherche.

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EXECUTIVE SUMMARY

OBJECTIVES

The Minister of Transport's Sustainable Development Strategy (SDS), which incorporates both internal stewardship activities and those that involve the transport sector at large, must be tabled in Parliament by December 1997.

This project focussed on methods to support the development of this strategy. *Sustainable Transport Technology: Framework for Action:*

- ***Identifies and categorizes technologies*** that potentially can support sustainable transport.
- ***Assesses and screens these technologies*** for detailed evaluation by Transport Canada.
- ***Comments on*** the applicability of the screened technologies and the federal government's possible role in supporting them.
- ***Develops practical criteria*** for evaluating their potential.

For the purposes of this research, ***sustainable transport technology*** is defined as *a technology that reduces consumption of non-renewable transportation modes, and is implemented in such a manner as to be supportive of safety, affordability, accessibility, and public values*.

In turn, ***sustainable transport*** is defined as *safe, efficient, effective, affordable transportation services developed and operated in a manner which minimizes the environmental effects of transportation*.

Sustainable development is *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*.

PRODUCTS

Four key products constitute the main results of the *Sustainable Transport Technology: Framework for Action*.

The first important product is a detailed *inventory* of sustainable transport technologies.

A second is the *categorization* of these technologies, according to type, mode, and possible impact. This allows the technologies to be compared and assessed systematically and consistently. Evaluation criteria for subsequent detailed assessment are appended.

These two products yielded the sustainable transport technology sub-categories that offered the broadest potential to reduce adverse impacts. They are: ***reduced resource consumption, advanced***

vehicle developments, alternative fuel powered vehicles, advanced engine developments, and ***traffic management.*** The detailed assessment of individual technologies should focus on these sub-categories.

Reduced resource consumption includes measures to reduce vehicle weight, such as the use of composite materials to replace steel in automobiles and buses, and to streamline the vehicle.

Advanced vehicle developments include advances in electric and hybrid vehicles (vehicles that can produce and store energy on board) as well as in hydrogen or hythane (a natural gas and hydrogen mixture) fuelled vehicles.

The *alternative fuel powered vehicle* sub-category includes propulsion systems fuelled by alcohol (ethanol, methanol), natural gas (CNG, LNG), and propane (LPG).

Advanced engine developments include measures such as ceramic engines, improved fuel combustion and energy storage systems (e.g., flywheels), that reduce adverse impacts of existing internal combustion engines.

Traffic management includes measures that optimize vehicle movement. These control technologies are referred to as intelligent transportation systems (ITS). Examples include systems that provide real-time travel information to drivers and authorities, minimizing delay; and electronic road pricing systems that help authorities to control the demand on transportation infrastructure.

Perhaps most important is a third product: two policy directions for achieving sustainable transport goals. The first direction comprises improvements or refinements to existing transport technologies and maintains (but improves) current consumption patterns. The second direction implies entirely new transport technologies and represents a complete change.

The two directions may be seen more clearly in sequence. This is because a shift from the first group of technologies to the second is eventually likely as benefits from the first group diminish and technologies in the second group come closer to achieving sustainable transport goals. In other words, current and near-term technological improvements eventually will generate limited improvements, whereas only the introduction of a new technology will achieve more substantial benefits. The current and near-term technological improvements are representative of the first group of technologies; the long-term technological improvements comprise the second group. The second group is necessarily more complex and costly than the first group.

A fourth product is the identification of possible roles or actions for the federal government, intended to develop, apply, and promote sustainable transport technologies along the aforementioned directions. Seven such roles and actions supporting these technologies are summarized below:

1. *Information broker* -- to serve as a central forum for the exchange of ideas, information, and new developments.

2. *Marketing broker* -- to promote the use of sustainable transport technologies and applications in all aspects of transport in Canada and around the world.

3. *Funding broker* -- to actively promote and link potential funding partners and sponsors.

4. *Standards development* -- to develop appropriate standardized measures of sustainability as a means of providing targets for Canadian technological developers, and identifying progress towards achieving SDS goals.

5. *Employer policies* -- to demonstrate the viability of the technologies, and field-test them prior to widespread commercialization.

6. *Policy development* -- to develop prototypical policies and practices, export these services to less developed countries, and coordinate efforts among federal, provincial, and municipal governments and agencies.

7. *Taxation and fiscal incentives* -- to develop taxation and fiscal policies in support of these technologies.

Another important role for the federal government would be to promote and encourage the shift from the first group of technologies to the second at the appropriate time and with the appropriate policy and fiscal framework.

RECOMMENDATIONS / NEXT STEPS

A recommended first step towards implementing the products is the detailed assessment of candidate technologies, with the criteria providing the evaluation framework.

An important second step would be the development of an action plan that details the implementation of the recommended policy directions and roles in Transport Canada and other federal departments and agencies, and establishes the mechanisms for broad, cooperative efforts with other governments, other public agencies, the private sector, academia, and research institutions.

Implementation of any specific action by the providers of transport services and/or the federal government requires a coordinated and supportive effort among behavioural, fiscal, and technological policies. None of the three policy groups alone can achieve sustainable transport goals. Nor is technology a panacea for all of society's problems. However, a coordinated, nation-wide effort could go far towards achieving sustainable transport goals. Finally, much depends on acceptance and use of sustainable transport technologies by the travelling public.

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1. INTRODUCTION

1.1 Context

The rapid technological advances of the post-war period brought significant improvements to Canada's economic development and standard of living. Less well understood in the public perception were the unintended effects of these advances on the environment, despite growing scientific documentation of significant impacts to the earth's resources, flora and fauna. The 1962 publication of Rachel Carson's *Silent Spring* was considered to be the first popular description of these impacts in North America, and was credited with playing a major role in making the public aware of environmental issues. Several initiatives were undertaken in Canada and elsewhere in the developed world; notably, legislation protecting the environment but also consideration of technological solutions to ensure energy conservation, pollutant reductions, recycling, etc. Reports such as the Club of Rome's *Limits to Growth*, further broadened the public's awareness of environmental issues.

Much of the impetus in these technological developments was economic rather than environmental. In particular, the oil shortages of the 1970s drove many of the technological advancements in vehicle and engine design (more efficient engines, lighter vehicles, etc.) although other environmental improvements also were introduced (e.g., catalytic converters and use of unleaded fuels). In turn, many of these advances were made possible by the parallel popularization of micro-computer and other electronic control technologies (such as electronic fuel ignition).[1]

By the late 1980s, increasingly evident manifestations of environmental degradation, globally and locally, made it impossible to ignore such effects as greenhouse gas emissions. The 1987 Bründtland Commission report, *Our Common Future* (a key author of which was Canada's Jim McNeil), attempted to relate economic and environmental sustainability.

In 1992, Canada signed the *Framework Convention on Climate Change*, under which Canada and other countries agreed to work to stabilize greenhouse gas emissions at 1990 levels by the year 2000. The *National Action Program on Climate Change* outlined the federal-provincial strategy for achieving this goal, and for subsequent actions beyond 2000. An important part of this strategy is the promotion of greater energy efficiency in all sectors of the Canadian economy. Since 1990, governments at all levels have introduced or broadened programs to reduce the market barriers to energy efficiency, and to accelerate the development and adoption of more energy-efficient technologies.[1]

1 It is noteworthy that many of the Canadian examples cited in *Silent Spring* concerning the degradation of flora and fauna were produced by scientists who -- although environmentally aware -- had as their initial interest the economic sustainability of these resources.

1.2 Purpose of Research

The *Sustainable Transport Technology: Framework for Action* provides input to the development of Transport Canada's sustainable transport strategy. The Minister of Transport's Sustainable Development Strategy (SDS), which incorporates both internal stewardship activities and those that involve the transport sector at large, must be tabled in Parliament by December 1997.

STATEMENT OF PURPOSE – *SUSTAINABLE TRANSPORT TECHNOLOGY: FRAMEWORK FOR ACTION*

- ***Identifies and categorizes candidate technologies*** *that potentially can support sustainable transport.*
- ***Assesses and screens these technologies****, for subsequent detailed evaluation by Transport Canada concerning their potential in a sustainable transport strategy for Canada, as input to the SDS.*
- ***Gives direction*** *concerning the applicability of the screened technologies, and the Federal Government's possible role in supporting these technologies.*
- ***Develops meaningful and practical criteria*** *for subsequent evaluation of the potential of the technologies.*

Overall, the purpose of this research can be described by the following quotation:

> The concept of sustainability ties together economic, environmental, social and energy goals, all of which affect and are affected by transportation. Which new technologies appear most promising for providing mobility at minimal cost and inconvenience to users, and how can they most effectively be brought to the market-place by public policy? [2]

1.3 Definition of Sustainable Transport Technology

Since the Bründtland Commission first proposed the concept of *sustainable development* in 1987, there have been innumerable attempts to develop ways of achieving it, in transport and in other human activities. Therefore, it is appropriate at the outset of this report to define what is meant by *sustainable transport technology*, and to identify technology's role in achieving sustainable transport and sustainable development goals. In doing so, we note that the definition of sustainability depends very much on the perspective. The purpose here is to develop workable definitions that are suitable for the purpose of this research.

First, what is sustainable transport technology? The definition used in this research is based on the Transportation Development Centre's (TDC) definition[3] which was modified by the study's expert panel (see Section 5.4).

SUSTAINABLE TRANSPORT TECHNOLOGY

> *A technology that reduces consumption of non-renewable transportation modes, and that is implemented in such a manner as to be supportive of safety, affordability, accessibility, and public values.*

Sustainable transport technologies are important components of sustainable transport, which in turn is a major element of an overall sustainable development strategy.

However, technology in itself is not a panacea. Although it may not achieve all of the desired goals, it has the potential to bring society closer to achieving its sustainable development objectives.

Figure 1-1 shows that the components of sustainable development -- economic activity, transport, environment, etc. -- are interrelated although transport is a derived output of the other human activities. It follows that the achievement of a sustainable transport strategy is a necessary condition for the achievement of a sustainable development strategy, and that a viable sustainable development strategy requires the integration of all component strategies.

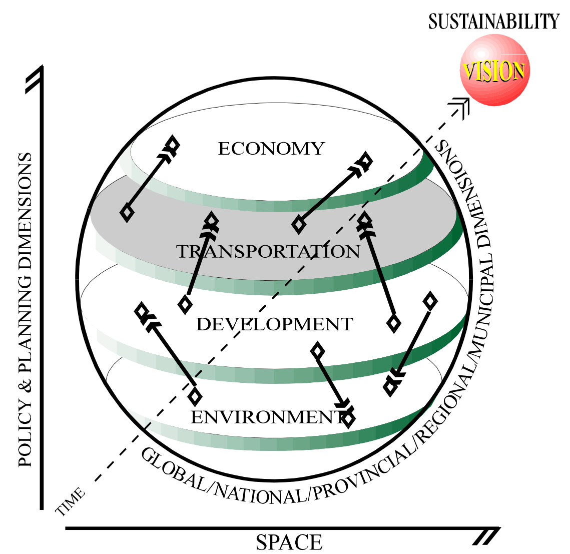

Figure 1-1. Components of Sustainable Development

A definition for sustainable development is shown in the box below:

SUSTAINABLE DEVELOPMENT

> *Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*[4]

The role of sustainable transport in sustainable development is captured by Transport Canada's *National Framework for Sustainable Transportation*, which defines the goal of sustainable transport as follows:

SUSTAINABLE TRANSPORT

> *To support the evolution of sustainable development through provision and use of safe, efficient, effective, affordable transportation services developed and operated in a manner which minimizes the environmental impacts of transportation.*[5]

Inherent in sustainable transport is the need to satisfy sustainability goals while ensuring that *basic mobility* also is achieved. This can be interpreted not only as minimizing redundancy in the transport system (e.g., by making more efficient use of existing capacity through ride-sharing, user pay, etc.) but also as ensuring that gaps in the transport system are filled seamlessly (e.g., regarding safety and accessibility). Sustainable transport also distinguishes between local and planetary impacts, especially air pollutants.[6]

The satisfaction of a sustainable transport vision must be based upon a policy framework. These policies must aim to minimize environmental impacts through pollution prevention, energy conservation, waste management, and bio-diversity, as follows:

> Working toward policies to enhance sustainable transportation suggests that three elements should be paramount in any consideration of the policies. First, transportation generated air pollutant levels should be limited in such a way that human health will not be adversely affected. Second, non-renewable energy resources must be harnessed not only to minimize the danger of their extinction but must be financially sustainable so that significantly high expenditures for fuel are not incurred through transportation operation and maintenance. Third, development of land-use policies should ensure that congestion does not persist.[7]

Sustainable transport policies can be categorized into three groups:[8]

1. ***Behavioural***, which describes how travellers and transport service suppliers consume transport services and related resources. Behavioural policies propose to modify these consumption patterns in a more sustainable manner. An example is York Region (Greater Toronto area), whose policy requires that any widening of its arterials beyond a basic four-lane cross section can be only for high occupancy vehicle (HOV) lanes. This increases the throughput (mobility) of persons rather than vehicles. Pertinent to this research is another example: the use of home computers for telecommuting, potentially reducing travel.

2. ***Fiscal,*** which regulates the consumption of these services and resources, and establishes the means of paying for them. An example is the introduction of user pay schemes on urban roads which, if appropriately applied, can at least recoup the external costs of pollution, resource consumption, etc., if not divert drivers to more environmentally-efficient modes. Funding for research and development of sustainable transport technologies is another example.

3. ***Technology***, which refers to the technological means and innovations that can be used to achieve sustainable transport policies, and is the subject of the *Sustainable Transport Technology: Framework for Action*. This group does not include transportation systems, or the behavioural factors that relate to a person's choice among competing modes. Rather, these candidate actions are found in the first group (behavioural policies) above.

The three policy groups are related, as shown conceptually in Figure 1-2. The figure shows that the three policy groups coalesce in the market which -- for the purposes of this research -- can be defined as the mechanism for implementing specific actions by travellers and by the providers of transport services. It is important to note that the implementation of sustainable transport actions requires a coordinated and supportive effort among the three policy groups.

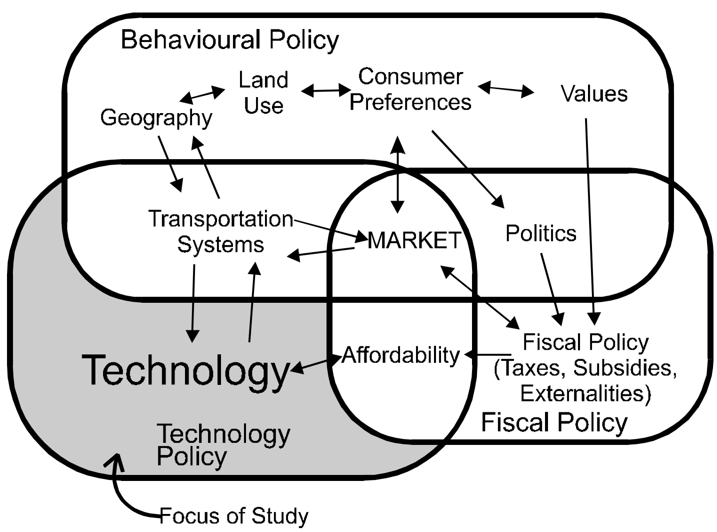

Figure 1-2. Components of Sustainable Transport

Figure 1-2 also shows that several related factors affect the relationship among the three policies. For example, consumer values (such as willingness to pay for sustainable technologies) are determinants of fiscal policies (e.g., the need to subsidize a technology from public funds), which in turn help define the affordability of a technology and its attributes (e.g., its design and applications). The figure also shows that many relationships are bi-directional.

Generally speaking, the term *technology* describes a machine or a mechanical process that has certain functions. The functions and attributes of *sustainable transport technologies* can be described thus:

> Technological developments [that] can have a very substantial effect on the efficiency with which resources are used, the extent to which non-renewable resources can be recycled, the level of sustainable yields, and the availability of non-polluting machines and processes.[9]
>
> Technologies ... that can reduce environmental risk substantially through significant technical advance.[10]
>
> In some respects, environmental impact of transport can already be reduced substantially by the more rapid diffusion of best practice technology, attention to which should be an important component of a technological policy. Further technological development can be envisaged which will reduce the adverse impacts of transport on the environment. But there are sufficient areas in which the potential of technology is so uncertain, or where the time scale of the necessary technological developments is likely to be so protracted, that a policy concentrating solely on research and development support is not enough. What will be required is a sophisticated appreciation of those time scales and balances and a strategy involving a whole range of instruments capable not only of getting the best technology we can, and getting the best out of the technology we have, but also of controlling the use of our technology to ensure that environmental standards are not irrevocably damaged while we wait for a technological fix that is unlikely to arrive in time.[11]

It should be noted that, as used in this study, a “technology” is distinct from a “system”. A system is the combination of two technologies, or of a technology with some exogenous factor. An example of a technology would be the vehicle used for transporting people or goods, while the system would include the vehicle and its supporting infrastructure.

1.4 Method of Research

This research required a systematic assembly and synthesis of a wide body of literature on technologies specific to sustainable transport, which was isolated in turn from an even broader literature on sustainable development. This required an extensive literature search, which focused on, but was not limited to, recent technologies (1990 onwards) for all modes of transport (urban and intercity, freight and passenger).

In addition to Delcan's in-house collection, sources included:

- Transportation Development Centre (TDC), Montreal
- Transport Canada Library, Ottawa
- CISTI (Canadian Institute for Scientific and Technical Information), Ottawa
- Transportation Association of Canada library, Ottawa
- The major North American and European data bases

The literature search focused on English-language sources, but relevant material in other languages also was assembled.

An information search on the Internet was also conducted. This captured mainly products and developments, but also identified key researchers and developers of sustainable transport technologies. This information is documented in a separate working paper submitted to TDC.

A context for the research is provided in Chapter 2. The context recognizes that the potential of a technology to achieve sustainable transport goals depends not only on its attributes but also on how it is used. Chapter 2 shows that the transport modes that are used most also generate the most adverse environmental impacts, and that these are primarily road modes (auto, small trucks, large trucks, urban transit buses, and intercity buses) followed by the air mode. It follows that the most effective technologies are likely to be those that can be applied to these most highly used modes.

Chapter 3 describes one of the two main products of this research: a descriptive listing of candidate sustainable transport technologies. Over 100 technologies were identified in the literature search. In order to provide a manageable reference for this research and for TDC, these were grouped according to five technology categories, by mode. A categorized list of technologies is presented in Chapter 3. A detailed description of each technology is included in the working paper mentioned above. A bibliography is also part of this document.

The second product is an assessment of the potential of the technologies to reduce adverse environmental impacts. This is done in Chapter 4, which uses the understanding of modal use and impacts (Chapter 2) to focus attention on those technologies that can be applied to road and air modes. The candidate technologies for these modes are then screened, according to their potential. The chapter also identifies criteria that TDC can use for a further detailed assessment of individual technologies. Chapter 5 discusses the implications of the results, the factors that affect them and possible opportunities and obstacles for the use of these screened technologies in achieving sustainable transport strategies in Canada. Chapter 6 concludes the research with a vision of a future with sustainable transport technologies, followed by a summary of key findings.

2. CONTEXT FOR THE RESEARCH

2.1 Overview of Transport's Contribution to Environmental Impacts

Chapter 2 relates the use of each major transport mode in Canada with its impacts on resource consumption (inputs) and environmental impacts (outputs). Section 2.2 profiles the demand for each major transport mode in Canada. Section 2.3 complements this with a profile of the impacts of each mode on the environment and on resource consumption. Together, the two profiles provide a measure of effectiveness, since -- all else being equal -- a sustainable transport technology will be most effective if it generates the greatest use and/or the greatest environmental benefits. Similarly, a particular candidate technology may not be worth pursuing if the mode to which it is applied is used only marginally or generates few adverse environmental impacts. The profile is used in the assessment of the technologies (Chapter 4).

The results of Sections 2.2 and 2.3 can be summarized in Table 2-1. The table provides a qualitative assessment of the utilization and environmental impacts of various modes. In Canada, road modes -- autos, trucks and buses -- dominate in both usage and environmental impacts. Air modes in Canada are next in importance and impact, whereas marine and rail have relatively minor usage and environmental impacts compared with the road modes. The results of Table 2-1 are used in Chapter 4 to pre-screen candidate technologies, in order to ensure that this research is focused upon the technologies that likely will be most effective in achieving sustainable transport goals.

2.2 Profile of Modal Use

Much of the sustainable transport literature focuses upon urban (as opposed to intercity) transport. However, the responsibility for urban and intercity transportation is divided among the three levels of government in Canada, with the Federal Government's primary responsibility being for interprovincial and international air, marine, and rail travel, as well as selected roads and bridges which fall under federal ownership. As a result, a single means of reporting modal use statistics does not exist, and there are several gaps in the available information. Furthermore, much of the available information is based upon estimates that were made with varying degrees of precision and according to different methods, depending upon the intended purpose. With these caveats in mind, a useful tabulation is provided by *Transportation in Canada: A Statistical Overview* (TAC, 1995), upon which the following summary is based.[2]

[2] Unless otherwise indicated, the information and figures presented in Sections 2.2.1 and 2.2.2 are derived from Nix, F.P., *Transportation in Canada: A Statistical Overview*, Transportation Association of Canada, Ottawa, 1995, pages 4-7.

TABLE 2-1. SUMMARY ASSESSMENT OF MODAL CONTRIBUTION TO ENVIRONMENTAL IMPACTS

MODE	MODAL SHARE IN CANADA	TREND IN USAGE		IMPACTS			
		CANADA	GLOBALLY	NON-RENEWABLE ENERGY CONSUMPTION*	OTHER RESOURCE CONSUMPTION**	AIR POLLUTION□	OTHER IMPACTS□□
Air (interurban)	**High**	**Increasing rapidly**	**Increasing rapidly**	**High**	Low	**Moderate**	**Moderate**
Rail - passenger (interurban)	Low	Decreasing	**Increasing slowly**	Low	Low	Low	Low
Rail - freight (interurban)	**High**	Decreasing	Stable	Low	Low	Low	Low
Marine - goods (international)	Low	**Increasing**	**Increasing**	Low	Low	Low	Low
Road - auto / small trucks	**High**	**Increasing steadily**	**Increasing very rapidly**	**High**	**High**	**High**	**High**
Road - large trucks	**High**	**Increasing rapidly**	**Increasing rapidly**	**Moderate or High**	Low	**Moderate**	**Moderate**
Road - intercity buses	Low	Decreasing	Stable	Low	Low	**Moderate**	**Moderate**
Urban transit – buses	**Moderate**	Stable	**Increasing slowly**	Low	Low	**Moderate**	**Moderate**
Urban transit – rapid transit	**Moderate**	Stable	**Increasing slowly**	Low	Low	Low	Low

Shaded cells indicate impacts that are ***increasing*** or which are ***moderate*** or ***high***.

* Non-renewable energy consumption includes non-renewable petroleum-based fuels.

** Other resources include those relating to the vehicle itself (e.g., materials), space requirements (e.g., land) and to the life-cycle use of the vehicle (e.g., waste).

□ Air pollutants include CO, CO_2, NO_X, SO_2, lead, hydrocarbons, particulates and volatile organic compounds (noting that leaded fuel no longer is available in Canada but is available elsewhere).

□□ Other impacts include health problems, traffic accidents, noise, vibrations, acid rain and global warming.

The summary is tabulated according to passenger and freight travel, consistent with the available information. Where possible, distinctions are made between urban and intercity transportation. **However, in all cases, the summary should be seen as a presentation of different perspectives, based upon not-always-compatible data sources.**

2.2.1 Passenger Mode Profile

The automobile is by far the dominant mode of intercity passenger transport in Canada, with air a distant second. This can be measured in two ways:

- *Passenger-kilometres*, which is a measure of travel output (number of people carried over what distance). Figure 2-1 shows that, in 1990, about 70 percent pf all passenger-kilometres in Canada were by auto. This proportion rises to 81 percent when small trucks (passenger minivans and pick-up trucks, etc.) are added. Air was the next most used mode, but still captured only 16 percent of domestic passenger-kilometres of travel. Bus and rail together constituted the remaining 3 percent.

- *Total trips*, which is an absolute measure of intercity travel activity. Figure 2-2 shows that, in 1992, Canadians made 158 million domestic intercity trips (one-way trips measured). The automobile (including minivans and pick-up trucks) accounted for 92 percent of these trips, making it by far the most used mode of transportation. Trips by air represented 4 percent of the total, with the remaining 4 percent comprising other modes.

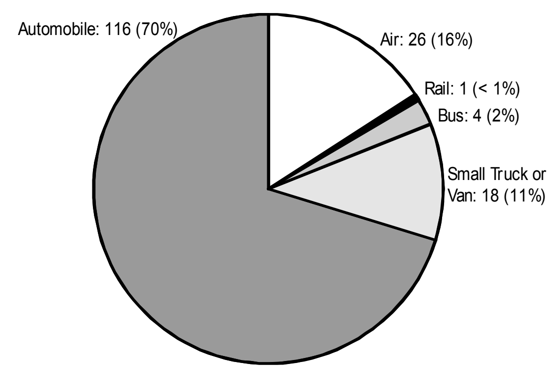

Figure 2-1. Domestic Passenger-Kilometres of Travel, 1990 (billion passenger-kilometres)
Source: Transportation in Canada: A Statistical Overview, p. 4.

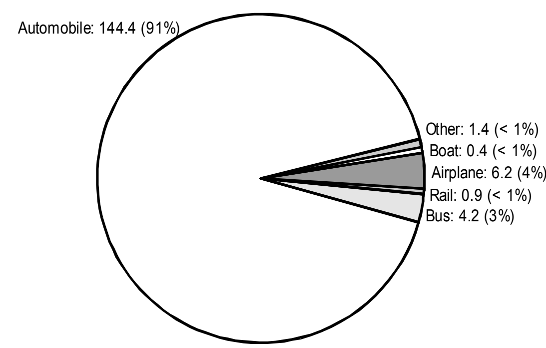

Figure 2-2. Domestic Intercity Travel, 1992 (million passenger-trips)
Source: Transportation in Canada: A Statistical Overview, p. 4.

Intercity travel in Canada has been growing. According to the Royal Commission on National Passenger Transportation, domestic intercity passenger-kilometres per person grew 1.9 percent per year between 1960 and 1990 (on average). In 1990, the average Canadian travelled over 6 000 kilometres on domestic intercity trips, compared with 3 500 kilometres in 1960.

The evidence is that the automobile will continue its dominant position (measured, for example, by the 2.3 percent annual increase in automobile registrations between 1983 and 1993; this exceeded the growth in the country's population). However, travel by air has increased fastest among all intercity passenger modes. Between 1960 and 1990, total domestic air passenger-kilometres increased 7.7 percent annually. Among the for-hire modes (air, bus, marine, rail), Figure 2-3 shows air travel's growing importance over time, measured in millions of passengers carried, while the intercity bus share has dropped significantly and rail's share has stagnated.[3]

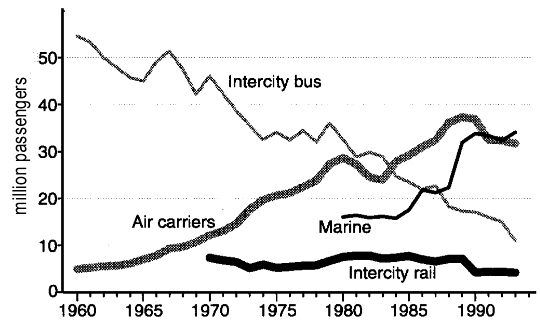

Figure 2-3. Passengers Carried by Intercity Carriers 1960 - 1993
Source: Transportation in Canada: A Statistical Overview, p. 5.

The preceding intercity profiles do not account for urban travel, nor do they always account for the growth in urban commutersheds, which now encompass once-isolated rural communities. For example, the total trips tallied in Figure 2-2 exclude trips of less than 80 km (one way distance) or regular commuter trips to work or school. However, there is evidence that these ex-urban trips will take on greater importance over time: During the 1980s, the fastest rates of population in the United States occurred in rural and semi-rural areas. [12] In Canada, this is exemplified by the continuing growth in commuters who work in the Greater Toronto Area while living in outlying communities in south-central Ontario, as shown in Figure 2-4. These commuters are willing to travel longer distances in order to capture the benefits of both a rural or semi-rural lifestyle and the job opportunities available in major urban centres. [13] Few data are available concerning the mode of use for these ex-urban trips; however, the indications are that the auto dominates here as elsewhere.

3 The marine modal data shown in Figure 2-3 contain some inconsistencies, and so are not directly comparable with the other modal information.

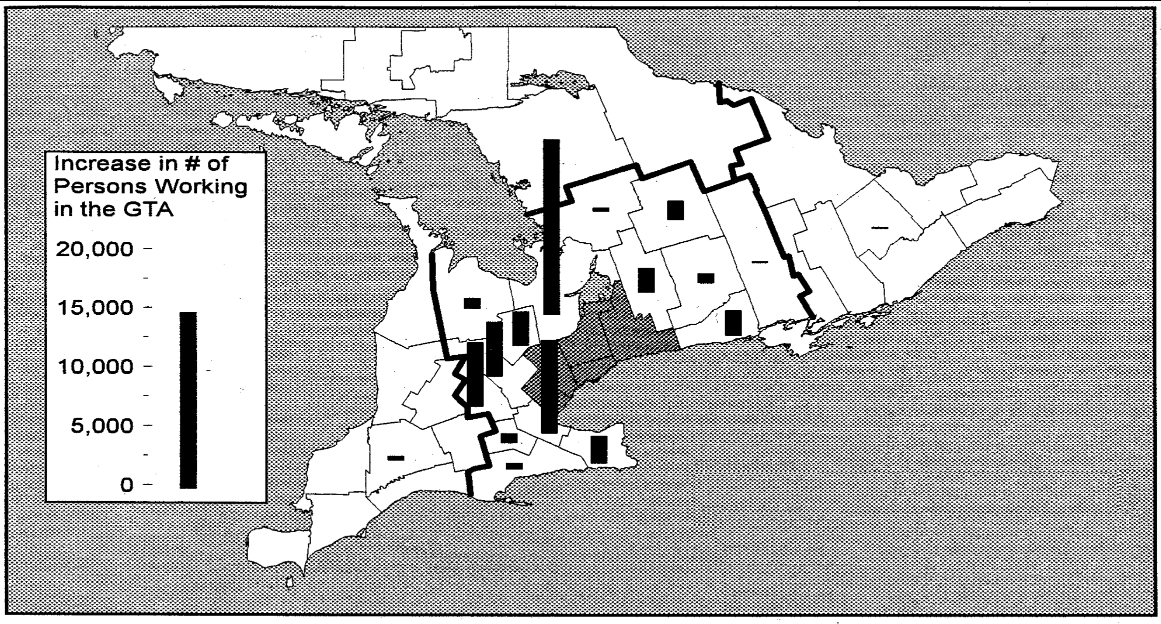

Figure 2-4. Increase in Commuting GTA, 1986 to 1991
Source: Use of Census Data for Transportation Planning: Experience and Applications in Ontario. Proceedings – 1996 TAC Conference

These trends, coupled with the increasing suburbanization of jobs and residents and the increased auto availability to households, have contributed to growth in urban travel by auto.

Public transport -- the primary alternative to urban auto use -- still captures a significant portion of the urban travel market in Canada's major urban centres, but experienced a significant drop in ridership after the Second World War. However, that drop has stabilized in recent years, as shown in Figure 2-5, which tracks these trends between 1950 and 1995 in per capita rides per year.

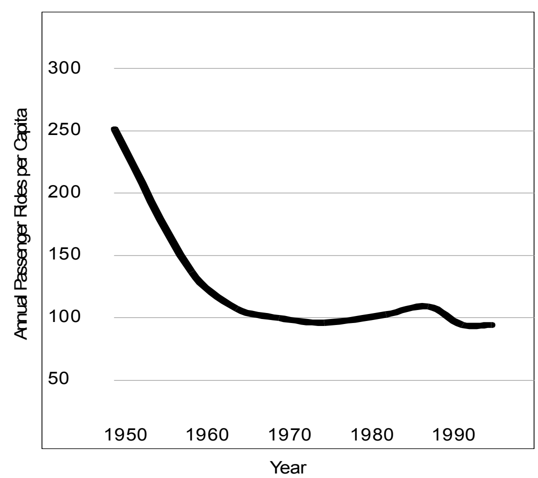

Figure 2-5. Annual Transit Passenger Rides Per Capita in Canada, 1950 - 1995
Source: Canadian Urban Transit Association

2.2.2 Freight Mode Profile

Rail and large trucks are the preferred modes of transport for domestic intercity freight movement, whereas marine is the dominant mode for international freight movement. For domestic and international freight movement combined (by tonnes carried), Figure 2-6 shows that 42 percent of total traffic was by water, 34 percent by rail and 24 percent by large truck in 1993/1994. However, these figures should be considered indicative only, because they do not include freight movement by small trucks (minivans, pick-ups, etc.), automobile, courier or bus. Also, multi-modal movements are not separated from the totals for each mode; as a result, the same unit of freight may be counted twice if moved both by truck and rail, for example. Finally, Figure 2-6 does not show the movement of gas and oil by pipeline; in terms of total tonnage these would be almost as large as rail or large truck (123 million cubic m which is equivalent to 200 million t).

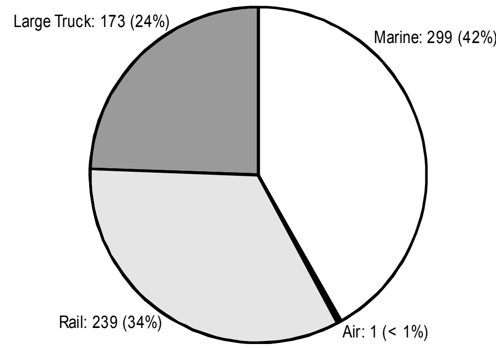

Figure 2-6. Intercity Freight, 1993-1994 (million t)
Source: Transportation in Canada: A Statistical Overview, p. 6.

Also indicative is the relative change in modal share over time. Figure 2-7 shows that rail's share in tonnage carried remained stagnant between 1980 and 1993, while truck's share -- subject to variations -- is again increasing. It should be noted that the truck share likely is under-reported, since the figure covers only for-hire trucking (as opposed to movement by in-house fleets) and includes only Canadian-based carriers. Therefore, the apparent reduction in the truck share after 1987 most likely reflects inconsistencies in reporting than any strong trend. Traffic by air is increasing steadily, although air still carries less than 1 percent of total intercity freight traffic.

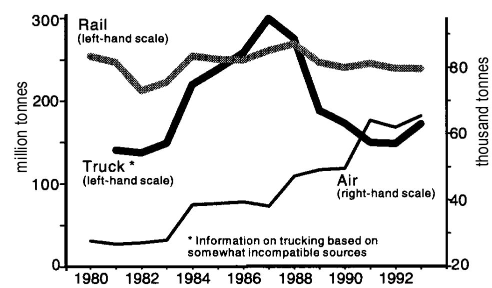

Figure 2-7. Freight Carried by Canadian-Domiciled Carriers, 1980 - 1993 (Truck tonnage based on somewhat incompatible sources. Therefore, post-1987 drop may reflect data rather than actual conditions.)
Source: Transportation in Canada: A Statistical Overview, p .6.

Estimates on urban freight movement are not collected regularly; however, the available information indicates that freight movement by truck dominates, and the proportion of trucks in the traffic mix is significant. In Ottawa-Hull, for example, a 1991 study estimated that there were over 150 000 truck trips made daily, compared with over 1 350 000 auto trips. However, truck traffic was growing faster than auto traffic. The study also noted that road congestion results in lost travel time and therefore in lost productivity, the costs of which are passed directly to the customer. These costs were estimated at $50 million annually. Given the short distances of these trips (10 km) and the large number of trips made per day (12), data tend not to be available for the amount of freight carried. However, since much of the freight circulating in cities originates in or is destined to other cities, much (but not all) of this tonnage is tallied in Figure 2-6. [14]

2.3 Impacts of Modes on Sustainability

This section describes the impacts of the various transport modes on the consumption of non-renewable energy sources and other resources (Sections 2.3.1 and 2.3.2 respectively), and as generators of air pollutants and other impacts (Sections 2.3.3 and 2.3.4 respectively). As with the previous section, the discussion draws upon different and not necessarily compatible sources, and estimates that were based upon different methods according to the intended purpose.

2.3.1 Non-Renewable Energy Consumption

Some simple statistics indicate the significance of transportation in the consumption of non-renewable petroleum-based fuels. **Due to discrepancies in the original data sources, these estimates must be considered as indicative but not necessarily definitive.** [15]

- **Transportation accounted for 27-30 percent of the secondary energy consumed in Canada** in 1994 (where primary energy is that consumed to prepare the secondary energy that is actually used in industry, transport, etc. An example of primary energy is that used to extract and refine oil, one product of which is the gasoline -- secondary energy -- used to power autos).[4]

- This was approximately the same proportion consumed in 1984.

- If measured by the increase in travel demand and the increased share of road and air modes, **secondary transportation energy consumption actually grew** by 33 percent between 1984 and 1994. However, half of this was offset by significant improvements to the energy efficiencies of vehicles (i.e., by the change in vehicle mix towards improved vehicles).

- Therefore, the ***net*** **increase in secondary transportation energy consumption** was 16 percent over the ten-year period. This increase, and the underlying factors, generally were consistent with the 15 percent net increase in total secondary energy consumption.

- **Sixty-five percent of transportation energy is consumed by passenger modes** (the remainder by freight modes). This translates to upwards of 17 percent of all secondary energy consumed (9 percent for freight).

- **Almost forty percent of the overall growth in freight transport energy consumption was due to modal shift**, rather than growth in demand, compared with 1 percent in passenger transport energy consumption. The major cause of this was a shift in freight movements from rail to truck modes.

[4] The range reflects gaps in the data that have been estimated, depending on the source (i.e., for non-airline air travel and marine freight modes).

- **Road modes dominated the consumption of passenger transport energy**, as shown in Figure 2-8. Almost 85 percent of passenger transport energy was consumed by autos, minivans, pick-ups, motorcycles, and other personal vehicles, with another 1.5 percent consumed by buses. Aviation consumed almost all of the remainder, with rail at 0.2 percent of the total. These proportions generally are consistent with output (passenger-kilometres) by mode (see Figure 2-1).

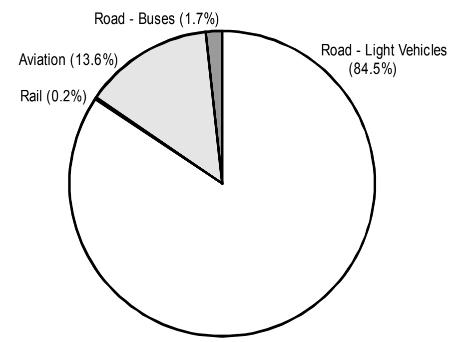

Figure 2-8. Distribution of Passenger Transportation Energy Use of Mode in 1994 (percent of petajoules)
Source: Energy Efficiency Trends in Canada, p. 34.

- **Motor gasoline comprised 82 percent of all passenger transport fuel consumed** in 1994, with most of the remainder made up by diesel fuel (3 percent) and aviation fuel (14 percent). Less than 2 percent was comprised of alternative transportation fuels (such as gasohol). These proportions have not changed significantly since 1984, nor has the distribution of energy use by mode (personal vehicles, buses, rail, and aviation).[5]

- The aforementioned **increase in travel demand was driven largely by the 3.6 percent annual growth in the use of personal vehicles**. This was due to such factors as increased household formation and increased household incomes which, combined, led to growth in personal vehicle availability. Personal travel also increased, as measured by increased travel distances of 1.7 percent annually. [6]

- An important determinant of personal vehicle use is the cost of fuel relative to vehicle operating costs. Over the ten-year period, **operating costs remained virtually constant**, while the **price of gasoline has dropped by almost 25 percent** (all costs measured in real prices).

5 The source does not explain why alternative transportation fuels continue to have a small usage, despite their technical feasibility and practicality of use. Possible reasons may include the relative availability of regular fuels (perceived lack of need to conserve regular fuel consumption, as occurred during the US energy shortages of the 1970s), the relatively low cost of regular fuels compared with other countries, the lack of distribution systems for alternative fuels, the lack of awareness of benefits, and the lack of incentives to make alternative fuels financially attractive.

6 These growth rates, cited in *Energy Efficiency Trends in Canada*, are based upon Statistics Canada surveys of vehicle use. A more detailed source of personal mobility could be derived from the many origin-destination surveys that have been conducted in most major urban areas. However, the cited results are consistent with those of the urban surveys.

- Also, **average new vehicle fuel *economies*** (fuel consumption per 100 km) **have remained relatively unchanged** between 1984 and 1994, for small autos, large autos, and light trucks (including minivans and pick-ups). This compares with significant increases between 1970 and 1984 in fuel economies of 2.2 percent, 3.7 percent and 3.7 percent, respectively. These findings reflect the major technological advances in personal vehicle energy efficiency that took place prior to 1984, in the face of the energy crises of the 1970s -- notably in body weight, aerodynamics, engine efficiency, and the drive train. Table 2-2 summarizes these changes over time. It can be seen that trends towards more powerful and heavier vehicles since 1984 have partially offset some of the earlier technological advances, despite the increasing use of micro-computers and electronic control of vehicle functions.

TABLE 2-2. TYPICAL NEW CAR CHARACTERISTICS FOR 1970, 1984, AND 1994

FEATURE	1970	1984	1994
Transmission	Automatic	Automatic	Automatic
Number of gears	3	3-4	4
Control	Mechanical	Mechanical	Electronic
Overdrive	None	Mainly manual transmission; some non-electronic	Electronic
Drive	Rear wheel	> 50% front wheel	Front wheel
Weight	> 4 000 lb	Approx. 3 000 lb	Approx. 3 200 lb
Drag	> 40	< 40	< 30
Tires	Belted	Radial	Radial
Engine	6-8 cylinders	4-6 cylinders	4-6 cylinders
Fuel control	Carburetor	40% fuel injection; mostly throttle body	Multi-point fuel injection
Valves per cylinder	2 valves	2 valves	2-4 valves
Horsepower	Approx. 135	Approx. 100	Approx. 140
Lab-tested fuel economy	13.3 L / 100 km	8.4 L / 100 km	8.3 L / 100 km

Source: *Energy Efficiency Trends in Canada*, Natural Resources Canada, Ottawa, 1996, page 39.

- As with passenger transport, **road modes (trucks) remained the dominant users of freight transport energy**, although to a lesser extent (72 percent). Marine modes used 16 percent, and rail the remaining 12 percent. (Data were not available for air.) There was little change in these shares between 1984 and 1994.

- **Diesel was the dominant fuel** (67 percent), followed by motor gasoline (21 percent), heavy fuel oil (9 percent) and other fuels (3 percent; including propane and natural gas).

- These shares reflect a **growth in diesel fuel consumption** (from about 55 percent of the 1984 total), caused by the greater use of diesel-fuelled mid-size and large vehicles in the truck fleet. There was a corresponding decrease in gasoline powered trucks. The use of other fuels (propane, natural gas, etc.) more than doubled but remains at 3 percent.

- **Transportation accounts for almost two-thirds of all petroleum consumption in Canada** overall; a proportion that has risen steadily over the last 35 years. Road modes (autos, trucks, buses, etc.) accounted for nearly 80 percent of all petroleum products consumed by the transportation sector in 1994. [16]

2.3.2 Other Resource Consumption

Technological efforts in reducing resource consumption have focused historically on energy use, in large part because of economic and political concerns. In contrast, comparatively little was said about the use of other resources, partly due to the importance of vehicle production in many developed (and now less developed) economies. However, growing awareness of the impacts of resource depletion and exploitation, coupled with structural changes in the global economy, has generated new interest in consumption of other resources.

Transport's impact on resource consumption is summarized succinctly by the following:

> The private automobile, which makes up the largest proportion of the world vehicle fleet, is a major consumer of resources. It consumes 60 percent of all natural rubber, 20 percent of steel production, 10 percent of aluminium products, and requires between 5 and 20 metres of road of every vehicle in the major cities. [17]

This statement describes three aspects of the consumption of other resources. These relate to the private automobile, but the issues are relevant to other modes as well.

- ***Vehicle.*** The substitution of materials and innovative design contributed to lighter vehicles (automobiles) in the wake of the 1970s energy crises (see Table 2-2). However, in the 1990s these gains have been offset partially by global population growth, increases in personal affluence and mobility, an emphasis on material over environmental benefit in less developed countries, and -- in North America -- the current popularity of heavier vehicles (minivans and sport utility vehicles).

- ***Space requirements for the vehicle***. This refers to the consumption of land for roads and parking but also in the urban sprawl that is made possible by widespread auto availability. In the 1990s, most major Canadian cities have prepared long-range transport plans that aim to limit the effects of sprawl, partly due to the costs of servicing new areas but also recognizing the need to maintain a viable and healthy quality of life in the existing city. Other impacts include the social and physical fragmentation of urban communities, visual intrusion on natural landscapes, and the disruption of natural habitats. At a local level, auto-oriented commercial areas (including fast-food outlets, suburban shopping centres, strip malls, gasoline stations, etc.) have expanded with sprawl. However, many Canadian cities have enacted or are considering by-laws and urban design guidelines that aim to reduce the visual and space intrusions associated with these developments, promoting both a sense of community and pedestrian- or transit-friendly alternatives to the auto. Notable among these efforts are neo-traditional neighbourhoods, in which homes, shopping and jobs are located close together (thereby minimizing the need to drive), infilling of older city neighbourhoods (closer to downtown jobs), and the promotion of higher density suburban development (which reduces the rate of land consumed per household and also can be served more efficiently by transit than can low-density dwellings).

- ***Life-cycle use of the vehicle***. Implications relate to the servicing and maintenance of the vehicle (including fuel storage, hazardous spills, etc.), and the operations and maintenance requirements for roads (e.g., chemicals used to keep roads free of snow, etc.). A further implication is the waste generated once the vehicle's useful life is over; an extreme result was the Hagersville (Ontario) tire fire a few years ago. Other impacts are the visual intrusion of automobile junkyards (but which also enable parts to be re-used), and the contribution of automobile waste to the demand for new or expanded land fill sites. Some automobile services have tried to address these issues by recycling used engine oil, for example, while provincial transportation ministries have attempted to use tire rubber in new road construction. Of interest is the recent German requirement that new automobiles be recyclable, so as to minimize waste. BMW and other German auto makers have developed and are testing vehicles that can be dismantled at the end of their working lives, for subsequent re-use in new automobiles or in other industries.

The three aspects are related to each other, but sometimes in conflicting ways. For example, the substitution of plastic for steel on automobiles reduces vehicle weight, which in turn reduces fuel consumption (all else being equal). However, plastic is less recyclable than steel, which means that the life-cycle benefit may be offset by the resource-reduction benefit (and vice-versa).[18] The complexity of the resultant trade-offs are not easily addressed, but they require coordinated analysis of several perspectives and scales.

2.3.3 Air Pollutants

In order to describe the generation of air pollutants by transport modes, it is useful first to categorize the major pollutants and their sources, as summarized in Table 2-3.

TABLE 2-3. MAJOR TRANSPORT AIR POLLUTANTS AND SOURCES

AIR POLLUTANT	SYMBOL	CAUSE / EMISSION SOURCE
Carbon dioxide	CO_2	Emitted by the combustion of fossil fuel
Carbon monoxide	CO	Results from incomplete combustion
Hydrocarbons	HC	Results from incomplete combustion
Volatile organic compounds	VOC	Results from incomplete combustion
Nitrogen oxides	NO_x	Generated at high combustion temperatures
Lead	Pb	Added to gasoline to attain the desired octane rating and greater volatility of combustion by-products. (Note: Although lead no longer is added to gasoline in Canada and in other developed countries, leaded gasoline is available in some less developed countries.)
Ethylene dibromide and dichloride		Added to gasoline to attain the desired octane rating and greater volatility of combustion by-products
Sulphur dioxide	SO_2	Due to the higher sulphur content of diesel
Fine particles		Present in diesel

The rapid growth in emissions from all sources of human activity is exemplified by Figures 2-9 and 2-10.[19] Respectively, these show that global emissions of nitrogen and sulfur oxides from fossil fuel combustion and global greenhouse gas concentrations have increased almost exponentially over the last century or two.

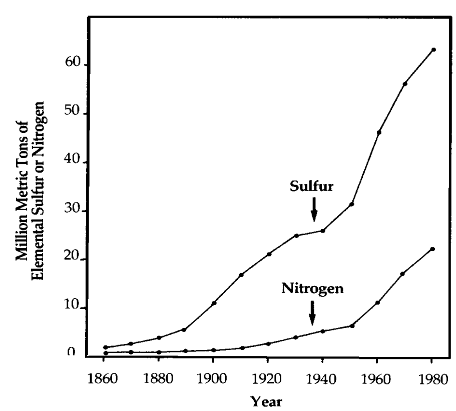

Figure 2-9. Global Emissions of Nitrogen and Sulfur Oxides from Fossil Fuel Combustion
Source: Transforming Technology: An Agenda for Environmentally Sustainable Growth in the 21st Century, p. 6.

In Canada, the transportation sector is a significant source of air pollutants -- in some cases, the dominant source. Table 2-4 breaks down the key pollutants generated by various modes, expressed as a percentage of *all* emissions in Canada.[20] The table shows that in Canada:

- Transportation is the principal source of CO (almost 75 percent of all CO emissions) and NO_x (60 percent).
- Except for particulates, road modes (autos, trucks, buses, etc.) account for the greatest portion of the transportation sector's share of air pollutants.

- Automobiles and light trucks (i.e., mainly passenger vehicles) alone account for almost three-quarters of the transportation sector's share of CO and VOC emissions, half the CO_2 emissions, and almost one-third of NO_x emissions.

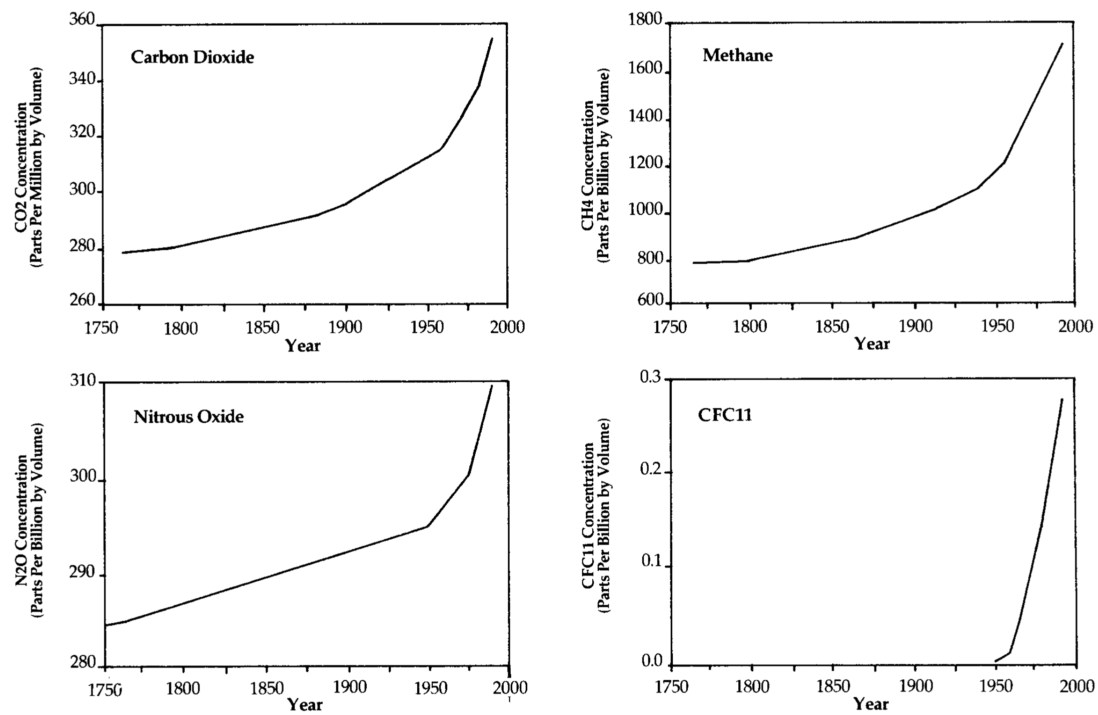

Figure 2-10. Global Greenhouse Gas Concentrations
Source: Transforming Technology: An Agenda for Environmentally Sustainable Growth in the 21st Century, p. 7.

TABLE 2-4. TRANSPORTATION SECTOR'S PROPORTION OF AIR POLLUTION IN CANADA (PERCENTAGE)*

MODE	CO	VOC	NO_x	PARTICULATES	CO_2
Road					
Autos / small trucks	53.4%	22.6%	19.4%	0.6%	15.4%
Large trucks	3.0	1.8	15.9	2.5	5.3
Sub-total	**56.4**	**24.4**	**35.3**	**3.1**	**20.7**
Rail	0.5	0.3	6.6	1.7	1.3
Air	0.5	0.3	0.9	0.1	2.5
Marine	0.9	1.2	2.3	0.4	1.5
Other**	15.2	4.8	15.2	5.1	4.6
TOTAL, Canadian Transportation	***73.5***	***30.9***	***60.4***	***10.4***	***30.5***
TOTAL, European Transportation	*--*	*49*	*61*	*--*	*21*

* Canadian emission levels for 1990, except 1993 for CO_2

** Includes propane and natural gas powered vehicles, emissions from tires, off-road use of gasoline, and diesel engines used in various machines (forestry equipment, etc.)

The table also compares the Canadian situation with that in Europe, for selected pollutants.[21] It can be seen that the two situations are similar for NO_2 (at 60 percent for both). In Europe, the transportation sector generates almost half the VOC emissions (49 percent), compared with less than one third in Canada (31 percent). On the other hand, the Canadian transportation sector is responsible for half again as much of the CO_2 emissions as its European counterpart (31 percent compared with 21 percent). These comparisons are indicative of both the importance of the transportation sector as a contributor to air pollution, and of the fact that the problem is by no means unique to Canada. However, the differences in VOC and CO_2 contributions may reflect the relative importance of different modes, the contributions of other sectors, technologies, regulations, etc.

While the data in Table 2-4 reflect a snapshot in time, Table 2-5 shows how CO_2 emission rates have changed over time.[22] These changes are important, because the level of CO_2 in the atmosphere is considered to be a primary indicator of sustainability, due to its important role in the greenhouse effect (increase in global surface temperatures).

Table 2-5 shows the following:

- In Canada, CO_2 emissions from transportation declined by 2 percent between 1980 and 1993. This compares favourably with the significant increases experienced over the same period in other OECD (Organization for Economic Cooperation and Development) countries and in the rest of the world (27 percent and 30 percent respectively). It also compared favourably with changes in CO_2 from all other sources in Canada, which increased by 3 percent.

- Improvements in vehicle technology (energy efficiency) were cited as a key source of the decline in Canadian transportation CO_2 emissions. However, there is concern that these may be offset by the growing proportion of minivans, pick-ups and sport utility vehicles in the personal vehicle mix -- all of which have greater fuel consumption than other passenger vehicles and which comprised 41 percent of new vehicles sold in North America in 1995.

- In Canada, the proportion of transportation as the source of CO_2 emissions declined by 1 percent, but the overall proportion still remained significant (30 percent).

- Per capita CO_2 emissions in Canada from both transportation and other sources have dropped significantly, but still remain higher than rates in other OECD countries and in the rest of the world.

- It was concluded that the reductions in these per capita emission rates are not dropping quickly enough to meet the global sustainability goal of a 60 percent global reduction in CO_2 emissions (80 percent in OECD countries). Per capita reduction rates of the order of 4.5 percent annually would be required in Canada to achieve this goal, compared with the 0.1 percent reduction rate observed between 1980 and 1993.

TABLE 2-5. EVOLUTION OF CO_2 EMISSIONS FROM TRANSPORTATION IN CANADA AND ELSEWHERE BETWEEN 1980 AND 1993

	CO_2 EMISSIONS (MILLION TONNES)		TRANSPORT AS A % OF ALL EMISSIONS	PER CAPITA EMISSIONS (TONNES)	
	FROM TRANSPORTATION	FROM ALL OTHER ACTIVITIES		TRANSPORTATION	ALL OTHER ACTIVITIES
	% CHANGE	% CHANGE	% CHANGE	% CHANGE	% CHANGE
Canada	**-2**	**3**	**-1**	**-0.9**	**-1.4**
Rest of OECD	**+27**	**-2**	**+15**	**+0.4**	**-1.3**
Rest of World	**+30**	**+29**	**0**	**+0.1**	**+0.1**

Source: Adapted from *Trends in carbon dioxide emissions from transportation in Canada and elsewhere: The challenge of sustainability*. Information sheet prepared by the Centre for Sustainable Transportation, Toronto, 1996.

Table 2-6 measures pollutant emissions by mode, as a function of output -- in this case, emissions per tonne-kilometres of freight movement.[23] On this basis, the table shows that rail generally is the "most desirable" mode, and truck is generally the least desirable. Marine ranks second behind rail, with mixed results for air and auto modes. On the one hand, Table 2-6 demonstrates the difficulties of profiling in a simple way the very complex characteristics of freight movement -- for example, it is not clear whether minivans and pick-ups fall under "autos" or "trucks," and different types of goods can be carried only on certain modes (e.g., bulk goods cannot be carried in autos or by air). As well, some local impacts may override the overall modal characteristics.

TABLE 2-6. RANKING OF MODES ON BASIS OF EMISSIONS PER TONNE-KILOMETRE

RANK	NO_X	VOCs	PARTICULATE MATTER	CO	CO_2
1 Most Desirable	Rail	Rail	Air	Rail	Rail
2	Marine	Marine	Rail	Marine	Marine
3	Auto	Auto	Marine	Air	Truck
4	Truck	Air	Auto	Auto	Auto
5 Least Desirable	Air	Truck	Truck	Truck	Air

Source of data: Kahn, A.M. *Energy & Environmental Factors in Freight Transportation*, Ottawa (1991) and Environment Canada, Pollution Data Analysis Division (1994). As referenced in Holloway, C.W., *Developing Priorities For Sustainable Transportation in Canada*, prepared for Transport Canada, Environmental Stewardship Team, Ottawa, March 1995, p. 5.

On the other hand, Table 2-6 demonstrates the importance of measuring pollutants by output -- i.e., one mode is not inherently more desirable than another if it is not used. This distinction is critical to the development of sustainable transport technology policies, because a significant portion of the public discussion on sustainable development promotes one mode over another (notably, passenger rail) in the absence of a thorough understanding of personal travel behaviour. This further emphasizes the need to coordinate technological policies with behavioural and fiscal policies (see Section 1.3).

2.3.4 Other Impacts

This section broadens the previous discussion on air pollution in two ways: It addresses the spatial, temporal and indirect impacts of air pollution, and relates these impacts to other pollutants.

Impacts of transportation differ in significant ways. Temporally, some impacts are instantaneous (e.g., noise). Some are pervasive but decay over time (e.g., hydrocarbons), while others are permanent (e.g., visual intrusion). Some impacts are cumulative (e.g., carbon dioxide).

Spatially, there is a clear distinction between those whose impacts are localized at the point of generation, and those that are transported on a continental or even global scale. Many of these result from the operation of vehicles, but also result from transport infrastructure location or design (e.g., visual intrusion), or of the resources and land consumed in the production of vehicles and infrastructure.[11]

At the global level, the main sustainability issue is the contribution of vehicle emissions to global warming (greenhouse effect). Under certain meteorological conditions, primary vehicle air pollutants can be transformed in the atmosphere to secondary pollutants such as ozone, acid aerosols (sulfate and nitrate) and fine particles. This pollution can be transported great distances by prevailing winds. As well, acid deposition occurs when the sulfur and nitrogen oxides are returned to the earth in rain. At the local level, the impacts of vehicle (auto) use are felt more immediately, and include acid rain, smog, traffic accidents, urban sprawl, infrastructure needs, and equity and locational impacts.[24]

The direct impacts of vehicle emissions generate further adverse impacts, notably on the well-being and health of the population. As well, the vehicle manufacturing and servicing industry produces solid toxic wastes and contributes to noise pollution. The various types of pollution generated directly by transport vehicles and their operation are summarized in Table 2-7, along with their causes and their impacts.[25]

TABLE 2-7. TYPES OF POLLUTION

TYPE	CAUSE	IMPACTS
Operation	Actual use of the different means of transport	• It affects the air, water and soil. • It produces noise and vibrations. • The effects in many instances are long-term and cumulative, although those caused by noise and vibrations are of an immediate and transient nature.
Air	Emission of chemical substances into the atmosphere which alter its composition, with harmful effects for human health, animal and plant life	• The effects of some pollutants remain within the vicinity of the source, where concentrations are highest, and thus have mainly a local impact as in the case of lead emissions. • The effects of other pollutants are suffered well beyond the vicinity of the source, as in the case of SO_2 emissions, which contribute to acid rain. • Pollutants can, however also have a global impact as in the case of CO_2 and other greenhouse gases, which affect the climate of the whole planet.
Water	Direct or indirect discharge of chemical substances into the aquatic environment resulting in the alteration of the quality or nature of the water ecosystems with detrimental effects on human health or animal and plant life	• Transport contributes indirectly to ground water pollution through vehicle emissions and aircraft emissions at take-off and landing. • Transport accidents involving dangerous or polluting goods can have direct or indirect effects on the water ecosystem. • Transport contributes directly to surface water pollution through operational discharges from barges and other vessels as well as through accidental discharges of dangerous or polluting goods carried by inland waterways.
Marine	Discharge of chemical substances into the sea or estuaries with harmful effects for the marine ecosystems resulting in hazards to human health and to animal and plant life	• Sea transport affects the marine environment through operational pollution.

TYPE	CAUSE	IMPACTS
Soil	Chemical or physical interference	• Transport contributes indirectly to soil pollution through operational discharges and directly in the case of accidental discharges of dangerous or polluting goods.
Vibration	• Road vibrations are caused almost exclusively by heavy goods vehicles or buses driving on roads which are structurally or in layout unsuitable for such vehicles. • Railway vibrations are determined by local ground conditions, the track bedding system as well as the weight, suspension, and speed of the train.	• Vibrations caused by aircraft on the ground have not led to major concerns since this type of nuisance is overpowered by the noise emissions of the engine.

All aforementioned impacts are summarized in the following paragraphs. It should be noted that the impacts are generated both by the inputs to transport (e.g., hydrocarbons) as well as its outputs (e.g., emissions). As well, localized impacts may vary according to specific conditions (for example, weather changes, accidents, congestion levels, etc.). However, these localized variations are included inherently in the broader picture.

AT THE GLOBAL LEVEL

GLOBAL WARMING (THE GREENHOUSE EFFECT)

Global warming is considered to be among the biggest problems facing humanity over the next century since, if current trends prevail, worldwide temperatures will rise steadily by 3°C by the end of the next century. This would generate local climate changes that are highly disruptive to established patterns of agriculture, as well as increased coastal flooding, mass human migrations, and the destruction of whole ecosystems.[6]

Figure 2-11 shows that global temperature has been rising over the last 150 years, commensurate with the Industrial Age, at an almost exponential rate of change.[26]

Global warming -- the "greenhouse effect" -- is characterized by the following:

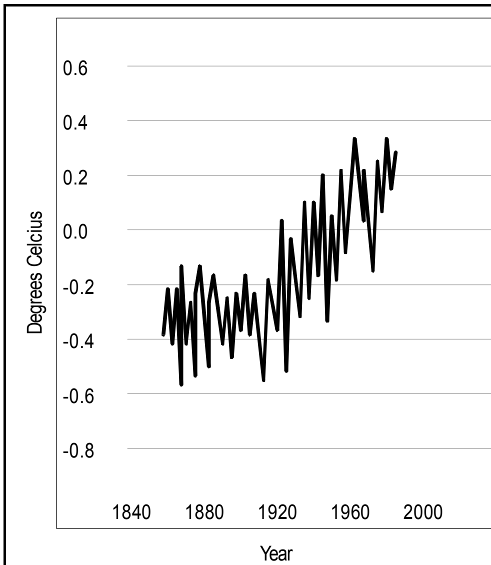

Figure 2-11. Global Temperature Changes, Relative to 1950-1979 Reference Period
Adapted from: Jones, P.D., T.M.L., Wigley and K.R. Britta, 1994

- Tropical deforestation and emissions of greenhouse gases, especially CO_2, methane, NO_x and chlorofluorocarbons (CFCs), are the principal causes of global warming.

- Carbon dioxide, methane and nitrous oxide contribute directly to the greenhouse effect and the climate changes that result, while nitrogen oxides, carbon monoxide and hydrocarbons contribute indirectly to the greenhouse effect. HC, NO_x and VOC also contribute to the buildup of ozone concentrations in the troposphere.

- Motor vehicles alone now contribute 17 percent of current global CO_2 emissions.[6]

- Dust, spray and particulate exhaust emissions are also a form of atmospheric pollution from road traffic.

OZONE DEPLETION

- The main contributor from road traffic to the depletion of the ozone layer are CFCs used in vehicle air conditioning systems.

- High altitude aircraft contribute significantly to the depletion of the ozone layer.

AT THE LOCAL LEVEL

ACID RAIN

Acid rain is a localized phenomenon that can be characterized as follows:

- Acid rain is generated especially by sulphur dioxide, nitrogen oxides and hydrocarbons.

- Acid rain causes forest damage, damage to buildings and destruction of soil quality.

- NO_x and sulfur dioxide (SO_2) contribute to acid rain.

- Nitrogen and sulfur oxides, together with unburnt hydrocarbons, are the principal components of acid rain.

SMOG

The major component of urban smog, ground-level ozone, is formed when two types of chemicals in fuel emissions -- NO_x and VOCs -- act together in the presence of heat and sunlight. This ground-level ozone contributes to respiratory problems and damages the foliage of crops and trees.[7]

Photochemical smog, the brown haze that causes health disorders, restricts visibility, erodes buildings and monuments, reduces crop yields, etc.

ACCIDENTS

Strictly speaking, transport accidents have not been considered to be a sustainability issue. However, accidents are included here as a means of referencing several topics: the wastage in resources (including human) that results; the possibility of hazardous material spills and subsequent environmental damage; and, the many mutual benefits that implementation of sustainable transport principles will have on reducing accident rates (i.e., improving safety) and vice versa.

The largest contributor to the total figure for external environmental and accident costs is road transport, which is responsible for 92 percent of the total. Air traffic has only a 6 percent share while rail and inland waterway shipping, with 1.7 percent and 0.3 percent respectively, are responsible for only a small proportion.

NOISE

Noise pollution from transportation sources represents an important health issue in OECD countries. About 40 percent of the population are disturbed by vehicle noise and more than 15 percent are regularly exposed to unacceptable levels[24].

HEALTH

Several health risks have been identified, notably:

- Health risks are triggered by photochemical smog, a mixture of gases and particles oxidized by the sun.
- Emissions of CO, NO_x, HC and PM have been shown to damage human health.
- HC and VOC increase the risk of cancer and respiratory disease.
- HC, VOC, lead, aldehydes, ethylene dibromide and dichloride have potential carcinogenic effects. CO and lead are poisonous to living organisms.
- Respiratory problems, decreased pulmonary function, and other health problems arise from direct exposure to NO_x and indirect effects of ozone formed from NO_x and hydrocarbons HC.
- The World Health Organization has concluded that diesel particulate is a probable human carcinogen.

3. CANDIDATE TECHNOLOGIES

3.1 Criteria for Selection of Candidate Technologies

The literature search uncovered a large number of perspectives on technologies for sustainable transport. However, the perspectives varied according to the topic at hand. Therefore, some judgment was required in order to differentiate and select candidates among them, in the following ways.

First, a distinction was made between "advocacy" literature (which promotes the use of technologies in sustainable transport strategies) and literature with a more technical basis. The "advocacy" literature provided a useful context for the role of technology, but tended to be too general for input to the candidate technology list.

Second, it was important to distinguish between technologies that were technically feasible *now* as opposed to concepts that represented, perhaps, some future idealized condition. *Current technical feasibility* implied that a technology was sufficiently advanced to one of several states: still experimental (but advanced beyond the conceptual stage); on the verge of becoming commercially feasible; commercialized; or in widespread use. The technology must have demonstrated applicability on a relatively large scale, and must have demonstrated at least the potential for reducing energy consumption, other resource consumption and pollutants emissions[27]. The concept of *practical applicability* expands *technical feasibility* to include technologies that have advanced beyond the experimental or prototypical stage, to commercialized or in-use applications that have demonstrated quantifiable benefits in energy and other resource consumptions and pollutant emissions.

Third, distinction is made between *technology*, which is the physical innovation that can be used to achieve sustainable transport, and *best practice technology*, which relates to the application of the innovation. The former is the main subject of this *Sustainable Transport Technology: Framework for Action*. Best practice technology implies education and awareness about technological innovations, as well as the complementary technological advances that are required in order to apply the basic sustainable transport technology. An example might be the use of ride-sharing software (a *best practice technology*) that allows the driver of a highly fuel-efficient auto (a *sustainable technology*) to optimize vehicle performance by carrying more people for the same energy consumption. Similarly, a sustainable technology developed initially for another application -- for example, paints that require fewer solvents -- may, under a best practice technology, subsequently be applied to transport.

3.2 Framework for Categorizing Technologies

In order to assess the potential of the large number of candidate sustainable transport technologies identified, it was necessary first to categorize the technologies in a systematic manner. A two-level categorization is used which comprises modes of transportation and technological categories.

Four modes -- road, rail, marine, and air -- are used. These are further sub-divided between urban and inter-urban applications, except for air. This allows a distinction between applications and environments. It also adheres to the way in which many of the technologies have been presented in the literature, much of which focused upon a single application for a technology (e.g., urban auto engines) that could be used in other applications and categories (e.g., inter-urban truck engines). It should be noted that bicycling and walking, which are strongly linked to sustainable transportation policies, could also benefit from the technologies associated with other modes.

Three technological categories were defined. These allowed the candidate technologies to be categorized not only by the different components of the vehicle, but also by its movement through space and time, as follows:

- Vehicle (e.g., the automobile, particularly its body, chassis, suspension, steering, and tires).[7]
- Propulsion (e.g., the automobile's engine, fuel, transmission, acceleration, and braking mechanisms).[8]
- Control (e.g., traffic management, information systems).

Table 3-1 shows the technology categories as well as various sub-categories which further characterize the technologies. It should be noted that our literature search identified several "systems" (such as the use of sustainable transport technology in Curitiba, Brazil). However, such combinations of two technologies, or of a technology with some exogenous factor were excluded from the technology categorization and screening.

[7] Electric and hybrid vehicles and hydrogen-fuelled vehicles have been categorized under the "vehicle" category because a new generation of vehicles is needed. As well, electric and hybrid vehicles are considered to have a long-term implementation period.

[8] Alternative fuel powered vehicles such as natural gas and alcohol fuel powered vehicles have been categorized under the "propulsion" category since technological developments are mainly related to the alternative fuel itself and not the vehicle. As well, alternative fuel powered vehicles are considered as having a short-term implementation period.

TABLE 3-1. TECHNOLOGY CATEGORIZATION

TECHNOLOGY CATEGORIES [28] 9	TECHNOLOGY SUB-CATEGORIES
Vehicle -- "carriage" in which passengers and goods are transported.	Resource consumption
	Advanced vehicle developments
Propulsion -- type of propulsion unit and method of transferring acceleration / deceleration forces.	Alternative fuel powered vehicles
	Electronic technology
	Advanced engine developments
	Exhaust after-treatment developments
Control -- means of regulating travel of one or all vehicles in a system, including spacing between vehicles and navigation aids.	Information systems
	Logistics
	Traffic management
	Advanced vehicle control systems

3.3 Identification and Categorization of Candidate Technologies

Using the selection criteria mentioned in Section 3.1, our literature search yielded approximately 50 candidate technologies for assessment. (In fact, almost 120 technologies were identified; however, many of these were minor variations of each other which were re-categorized as a single technology.) Table 3-2 counts the number of candidates by technology and mode, according to the technology categories outlined in Table 3-1. (All 120 technologies were included in this count.) The counts tabulate the number and type of applications as expressed in the literature, which means that many are listed more than once; however, these listings do not account for other possible applications. The table shows the following:

- The greatest number of applications was cited for:
    - Road modes -- automobile, truck and bus.
    - Urban road modes (but inter-urban for all other modes).
    - Propulsion technologies, followed by the control and vehicle categories.

In conclusion most technologies focused on reducing energy consumption and pollution in automobiles, trucks, and buses.

9 Infrastructure was not addressed, even though it may contribute to fuel saving, because the maintenance, rehabilitation, etc. of the road network is related to the "system" or to construction technologies and not to the technologies addressed in this study.

3.4 Trends in Technology Research and Development

It is appropriate to provide a context for the identification and categorization of the candidate technologies by outlining some of the major ongoing developments. The following discussion addresses key developments in the vehicle, propulsion, and control categories.

3.4.1 Vehicle

3.4.1.1 Reduced resource consumption

- ***Vehicle weight and streamlining***. The primary emphases in vehicle design have been reducing vehicle weight (therefore reducing energy requirements) and streamlining the vehicle. Most efforts have addressed road modes, primarily the auto but also trucks and buses. As Table 2-2 shows, the greatest reductions in auto vehicle weight occurred in the wake of the 1970s oil shortages, with average weights actually increasing in the 1994 model year compared with 1984, as a result of the growing popularity of minivans, sport utility vehicles and pick-up trucks as personal vehicles. Other reductions have been attributed to the substitution of lighter materials for steel and cast-iron components, including magnesium, plastics, aluminum, and high-strength low-alloy steel, and provide the necessary strength, resistance to heat and stress and design flexibility. The use of plastics, which represented 8-11 percent of the weight of western autos in the 1985 model year, is expected to grow significantly, due to their low cost.[29]

- ***Composite materials.*** The use of composite materials to replace steel in automobiles also is being tested. A consortium of American auto makers recently demonstrated that automobiles with composite front-ends could meet U.S. government crash-safety standards in a recent 35 mph (55 kph) controlled crash test. The materials tested were polymers reinforced with glass fibres, which weigh 25 percent less than the steel parts they replaced. In a crash, these materials are designed to fracture and crumble, compared with traditional metals, which buckle and fold. However, two significant impediments to their use in mass production vehicles still must be overcome: the raw materials remain expensive, and the manufacturing processes are inefficient and costly (both compared with existing materials and processes).[30]

TABLE 3-2. TECHNOLOGY CATEGORIZATION BY MODE
(SHOWING NUMBER OF TECHNOLOGIES FOR EACH CATEGORY)*

TECHNOLOGY**	ROAD		RAIL		MARINE		AIR
	URBAN	INTER-URBAN	URBAN	INTER-URBAN	URBAN	INTER-URBAN	INTER-URBAN
Vehicle -- "carriage" in which passengers and goods are transported.	25	14	4	4	7	7	4
Propulsion -- type of propulsion unit and method of transferring acceleration / deceleration forces.	49	14	1	1	4	4	1
Control – means of regulating travel of one or all vehicles in a system, including spacing between vehicles and navigation aids.	22	10	5	6	6	7	9

* Technologies counted once for *each* applicable category (i.e., multiple counting).
** Definitions adapted from V.R. Vuchic, *Urban Public Transportation Systems and Technology*, Prentice-Hall, Englewood, NJ, 1981.

Composite carbon fibre body panels, introduced in Germany in 1990, can reduce the weight of urban public transit buses by over 40 percent compared with conventional buses which, when combined with smaller engines and tires (which are made feasible by the lighter vehicle), have resulted in fuel savings of 60-70 percent[27]. The reduction of truck and bus rolling resistance, air resistance and gross vehicle weight relative to load (occupancy) space can reduce energy consumption and pollution by 10 percent; however the additional 20 percent to the vehicle cost has prevented widespread use.[31]

3.4.1.2 Advanced vehicle developments

- ***Electric and hybrid vehicles*** also have shown some promise in recent years. Although electric vehicles (EVs) emit no pollutants, they may ultimately generate a net increase in pollutants compared with autos, depending upon how the electricity was produced initially. EVs differ from vehicles powered by internal combustion (IC) engines in the drivetrain and electricity source. On board electricity generation and storage technologies continue to be the limiting factors inhibiting the wide-spread commercialization of EVs, notwithstanding recent advances and tests in the United States. Hybrid vehicles have the means to produce and store energy on board, with the most common type of hybrid vehicle being one with a small IC engine-driven electricity generator [27].

- ***Hydrogen-fuelled vehicles.*** In Canada, the Ballard fuel cell has attracted considerable attention as a means of pollutant-free propulsion. The fuel cell is an electro-chemical device that converts fuel energy directly into electricity, without combustion. It uses hydrogen and oxygen as input, with water (H_2O) being the sole "emission". Recent developments have reduced the cell's size requirements and the hydrogen fuel tanks to permit practical usage in large vehicles (although not yet in automobiles). Current prototypes have a range of 250 km on one tank of hydrogen. With its partner, Daimler-Benz of Germany, Ballard has developed prototype buses that are to be tested in 1997 in Vancouver and Chicago; in addition to testing their practical operational feasibility under actual service conditions, the tests will compare the cost-effectiveness of these buses with regular diesel buses. Daimler is now examining ways of producing hydrogen on board from methanol, rather than storing hydrogen in bulky storage tanks, in order to reduce the weight required for the tanks (and, therefore, the technology's price) and provide longer vehicle ranges[31].

  Also in Canada, NovaBUS Corporation, in conjunction with Hydro Quebec, has developed a prototype "hythane" urban transit bus. The bus operates on a mixture of 80 percent natural gas and 20 percent hydrogen, and is currently being tested in regular service in Montréal. Natural gas urban transit buses are available commercially, but at prices approximately 25 percent greater than comparable diesel buses; as well, bulky roof tanks are required to store the large volume of fuel required [27].

3.4.2 Propulsion

3.4.2.1 Alternative fuel powered vehicles

Alternative fuels have been promoted as a means of reducing both the consumption of fossil fuels and the generation of pollutants. These include alcohol fuels (ethanol and methanol), natural gas, and electricity (battery-powered vehicles). In the Netherlands, liquefied petroleum gas (LPG) is being advocated for heavy-duty vehicles (buses) through such measures as subsidized fuel prices. Compared with compressed natural gas (CNG) which is also an environmentally sounder alternative to gas or diesel fuel, LPG weighs less (thereby requiring a lighter tank), emits less pollutants and is easier to refuel[31].

- ***Natural gas powered vehicles.*** Of particular interest to Canadian technology developers are natural gas vehicles (NGV), powered either by CNG or by liquid natural gas (LNG). CNG is more commonly used, primarily in fleets of light vehicles (e.g., taxis). In Canada, most of the 36 000 NGVs represent conversions from gasoline powered vehicles (which can now operate on CNG or gasoline). Penetration of NGVs into the private market has been limited, due to the initial costs of conversion (estimated at $2 600 to $3 400 per vehicle), shorter ranges, relatively few fuelling stations, some early developments problems with natural gas fuel systems and concerns about resale value. However, fuel costs are substantially lower than for regular gasoline. Ford and Chrysler offer “original equipment” NGVs, but at a premium of $4 700 to $8 200 over comparable gasoline-powered automobiles and light rucks. Although only modest growth in NGVs has occurred in Canada since 1983, when federal government grants to subsidize the cost of conversions became available, Canadian equipment manufacturers have been active in addressing some of the aforementioned drawbacks. However, Canadian firms have developed a leadership role in NGV technology and applications compared with the United States, where the technology has not been widely used. To date, the continued availability of low-priced gasoline fuel has precluded a broader penetration of NGV technology in North America. However, if the growing interest in low-polluting technologies continues (due, for example, to California’s Ultra Low Emissions Vehicle standards and targets), the demand for NGVs -- and for Canadian technologies -- is expected to grow [27].

- ***Advanced Engine Developments***. Advanced engine developments aim at reducing the adverse impacts of existing internal combustion engines.

  Efforts to increase auto engine efficiency have been underway in several areas, including improving fuel combustion, reducing engine warm-up time, stratifying the fuel mix (i.e., air-to-fuel mixtures that are appropriate to performance and efficiency objectives), increasing the number of gears via continuously variable transmissions, energy storage systems (including fly wheels, high-power batteries and ultracapacitors), widespread use of electronic control technology (e.g., electronic fuel injection), more efficient electrical systems, energy recovery systems (to recover exhaust and braking energy), ceramic engines, and lean-burn motors[29]. However, the use of direct injection (a type of fuel mix stratification) as a means of reducing automobile fuel consumption illustrates some of the practical problems that remain with many of these technologies, including reductions in engine power and increased pollutants (air and noise). In addition, there remain concerns about the durability and reliability of some technologies over actual vehicle life-cycles (e.g., ceramic engines), as well as ensuring cost-competitive manufacturing processes.

3.4.3 Control

The optimization of vehicle movement is characterized by several control technologies often referred to generically as intelligent transportation systems (ITS); notably information systems which provide real-time travel information to the driver and to the authorities monitoring a road, so as to minimize delays. ITS comprises several technologies that link the driver, vehicle, and infrastructure into an integrated system.

3.4.3.1 ITS

The purpose of ITS is to provide real-time *route guidance* to drivers as they prepare for a trip, as well as during the trip. The object is to allow trips to be made efficiently and to avoid potential difficulties (e.g., congestion or bottlenecks). In addition to optimizing resource consumption (e.g., fuel used while waiting in congested traffic), other potential benefits include increased driver comfort and improved road safety. Route guidance also allows authorities to optimize the use of existing capacity, thereby avoiding the need for new capacity, and to manage more effectively incidents as they arise. Other benefits include improved personal security, monitoring of vehicle operating conditions (e.g., automatically notifying authorities of on-board problems) and faster processing of goods vehicles through international borders (e.g., through electronically-coded manifests, etc.).

There are several ITS initiatives underway around the world, including *ITS America* (United States), *DRIVE* and *PROMETHEUS* (Europe) and *VERTIS* (Japan). In Canada, an ITS roundtable was set up under the auspices of the Transportation Association of Canada, and has recently been replaced by *ITS Canada*, an independent association. These initiatives address various or all facets of ITS, including the development of the information that is to be transmitted to drivers (pre-trip or on-board), the means of transmitting this information, the means of receiving this information, the associated infrastructure for monitoring conditions and tracking vehicle movements, and protocols to ensure common data and technological standards in all of the preceding elements. In addition to the ongoing development of new technologies, other issues that remain to be addressed are organization (including the need for partnership among transport authorities, telematics and telecommunications providers, equipment and vehicle manufacturers, and information providers); legal considerations (including the use of in-vehicle ITS equipment, personal privacy, access to information, compliance with various regulations, liability, etc.); and financial (including pricing of services, sale of data, breakdown of investment and operating costs, financial backing, etc.) [31].

Canadian ITS activity is not at the same level of the United States, Europe and Japan. However, Canadian governments, suppliers and universities have developed strengths in particular applications; notably, in ATIS (advanced traveller information systems, such as the Visual Communication Network), ATMS (advanced traffic management systems, such as COMPASS) and APTS (advanced public transit systems)[27]

3.5 Listing of Candidate Technologies

Examples of candidate technologies that were used in the assessment are presented in Table 3-3. The technologies are grouped by category and sub-category.

All candidate technologies (approximately 50) have been compiled in a working paper submitted to TDC.

Table 3-3. Examples of Supportive Sustainable Technologies

TECHNOLOGY CATEGORY	TECHNOLOGY SUB-CATEGORY	EXAMPLES
Vehicle	Resource consumption	weight reduction; drag reduction; rolling resistance reduction; use of composite materials; life-cycle design and manufacturing (recycling)
	Advanced vehicle developments	electric and hybrid vehicles; hydrogen-fuelled vehicles; advanced technology transit bus; new generation tires
Propulsion	Alternative fuel powered vehicles	alcohol fuel (ethanol, methanol) powered vehicles; natural gas (CNG, LNG) powered vehicles; propane (LPG) powered vehicles; fuel cell powered vehicles
	Electronic technology	electronic sensors
	Advanced engine developments	engine warm-up time reduction; increased number of gears; ceramic engines; innovative cooling systems; photovoltaic cells; all-composite tanks; carbon-fiber superflywheel; ultra-light weight alloys; ultracapacitors
	Exhaust after-treatment developments	catalytic converters
Control	Information systems	travel information; navigation
	Logistics	reservation systems; fleet management systems
	Traffic management	traffic controls; electronic road pricing
	Advanced vehicle control systems	automated guided vehicles; drivetrain technology

4. TECHNOLOGY ASSESSMENT

4.1 Approach

This chapter assesses the potential of the candidate technologies to reduce adverse environmental impacts. The assessment uses a screening framework, which combines the criteria described in Tables 2-1 and 3-1 as follows. **The evaluation focuses upon those modes having the greatest impact and usage, as defined in Chapter 2; namely, road and air**. Road modes are further divided according to the size and type of vehicle. This results in a total of four screening tables (Tables 4-1 through 4-4), as follows:

1. Road - autos and small trucks (minivans and pick-ups) (Table 4-1).
2. Road - large trucks and intercity buses (Table 4-2).
3. Road - urban transit buses (Table 4-3).
4. Air (Table 4-4).

Each table groups technologies by category and sub-category for each mode or sub-mode. **The principal means of assessment is by impact reduction potential, as defined by the four categories described in Sections 2.2 and 2.3 (non-renewable energy consumption, other resource consumption, air pollutants and other impacts).** The potential reductions are assessed qualitatively as low, moderate and/or high, based upon the literature.

The goal of the screening assessment is to identify technology sub-categories having moderate potential (or better) to reduce these impacts.

The tables also show two other columns. For each sub-category, these assess the likely implementation period -- a measure of when the technology is likely to be available for commercial use -- and current Canadian research and development efforts (a “reality check” aimed at matching R&D policies and strategies with state of the art in Canada, all else being equal). The assessment is qualitative, but is again based upon the literature. The two columns are not used in this assessment, but are applied in Chapter 5 to help develop appropriate sustainable transport technology strategies for the screened sub-categories.

TABLE 4-1. SCREENING OF ROAD MODE TECHNOLOGIES (AUTOS AND SMALL TRUCKS)

TECHNOLOGY CATEGORY	TECHNOLOGY SUB-CATEGORY	IMPACT REDUCTION POTENTIAL				IMPLEMENTATION PERIOD	CURRENT CANADIAN R&D EFFORTS
		NON-RENEWABLE ENERGY CONSUMPTION*	OTHER RESOURCE CONSUMPTION**	AIR POLLUTION†	OTHER IMPACTS††		
Vehicle	Resource consumption (e.g., aerodynamics, materials, tires, recycling)	**moderate**	**moderate**	**moderate**	low to moderate	near term	low
	Advanced vehicle developments	**moderate**	**moderate**	**high**	**moderate**	long term	low
Propulsion	Alternative fuel powered vehicles	**high**	**high**	**high**	**moderate**	near term	moderate
	Electronic technology (e.g., sensors)	low to moderate	nil	low to moderate	low to moderate	near term	low
	Advanced engine developments (e.g., energy storage systems)	**moderate to high**	**moderate**	**moderate**	**moderate**	long term	low
	Exhaust after-treatment developments (e.g., catalytic converters)	nil	neutral	low	low	near term	low
Control	Information systems (e.g., travel information, navigation)	low to moderate	nil	low to moderate	**moderate**	near term	low to moderate
	Logistics (e.g., reservation systems, fleet management systems)	low to moderate	nil	low to moderate	low to moderate	near term	low to moderate
	Traffic management (e.g., traffic controls, electronic road pricing)	**moderate**	nil	**moderate**	**moderate**	near term	low to moderate
	Advanced vehicle developments (e.g., automated vehicles)	low	**moderate**	nil	**moderate**	long term	low

Shaded cells indicate impact reduction potentials that are *moderate* or *high*.

* Non-renewable energy consumption includes non-renewable petroleum-based fuels.
** Other resources include those relating to the vehicle itself (e.g., materials), space requirements (e.g., land) and to the life-cycle use of the vehicle (e.g., waste).
† Air pollutants include CO, CO_2, NO_X, SO_2, lead, hydrocarbons, particulates and volatile organic compounds (noting that leaded fuel no longer is available in Canada but is available elsewhere).
†† Other impacts include health problems, traffic accidents, noise, vibrations, acid rain and global warming.

TABLE 4-2. SCREENING OF ROAD MODE TECHNOLOGIES (LARGE TRUCKS AND INTERCITY BUSES)

TECHNOLOGY CATEGORY	TECHNOLOGY SUB-CATEGORY	IMPACT REDUCTION POTENTIAL				IMPLEMENTATION PERIOD	CURRENT CANADIAN R&D EFFORTS
		NON-RENEWABLE ENERGY CONSUMPTION*	OTHER RESOURCE CONSUMPTION**	AIR POLLUTION†	OTHER IMPACTS††		
Vehicle	Resource consumption (e.g., aerodynamics, materials, tires, recycling)	**moderate**	**moderate**	**moderate**	low to moderate	near term	low
	Advanced vehicle developments	**moderate**	**moderate**	**high**	**moderate**	long term	low
Propulsion	Alternative fuel powered vehicles	**high**	**high**	**high**	**moderate**	near term	moderate
	Electronic technology (e.g., sensors)	low to moderate	nil	low to moderate	low to moderate	near term	low
	Advanced engine developments (e.g., energy storage systems)	**moderate to high**	**moderate**	**moderate**	**moderate**	long term	low
	Exhaust after-treatment developments (e.g., catalytic converters)	nil	neutral	**moderate**	low	near term	low
Control	Information systems (e.g., travel information, navigation)	low to moderate	nil	low to moderate	**moderate**	near term	low to moderate
	Logistics (e.g., reservation systems, fleet management systems)	low to moderate	nil	low to moderate	**moderate to high**	near term	low to moderate
	Traffic management (e.g., traffic controls, electronic road pricing)	**moderate**	nil	**moderate**	**moderate**	near term	low to moderate
	Advanced vehicle developments (e.g., automated vehicles)	low	**moderate**	nil	**moderate**	long term	low

Shaded cells indicate impact reduction potentials that are *moderate* or *high*.

* Non-renewable energy consumption includes non-renewable petroleum-based fuels.
** Other resources include those relating to the vehicle itself (e.g., materials), space requirements (e.g., land) and to the life-cycle use of the vehicle (e.g., waste).
† Air pollutants include CO, CO_2, NO_X, SO_2, lead, hydrocarbons, particulates and volatile organic compounds (noting that leaded fuel no longer is available in Canada but is available elsewhere).
†† Other impacts include health problems, traffic accidents, noise, vibrations, acid rain and global warming.

TABLE 4-3. SCREENING OF ROAD MODE TECHNOLOGIES (URBAN TRANSIT BUSES)

TECHNOLOGY CATEGORY	TECHNOLOGY SUB-CATEGORY	IMPACT REDUCTION POTENTIAL				IMPLEMENTATION PERIOD	CURRENT CANADIAN R&D EFFORTS
		NON-RENEWABLE ENERGY CONSUMPTION*	OTHER RESOURCE CONSUMPTION**	AIR POLLUTION†	OTHER IMPACTS††		
Vehicle	Resource consumption (e.g., aerodynamics, materials, tires, recycling)	**moderate**	**moderate**	**moderate**	low to moderate	near term	low
	Advanced vehicle developments	**moderate**	**moderate**	**moderate**	**moderate**	long term	moderate to high
Propulsion	Alternative fuel powered vehicles	**high**	**high**	**high**	**moderate**	near term	moderate
	Electronic technology (e.g., sensors)	low to moderate	nil	low to moderate	low to moderate	near term	low
	Advanced engine developments (e.g., energy storage systems)	**moderate to high**	**moderate**	**moderate**	**moderate**	long term	low
	Exhaust after-treatment developments (e.g., catalytic converters)	nil	neutral	**moderate**	low	near term	low
Control	Information systems (e.g., travel information, navigation)	low to moderate	nil	low to moderate	**moderate**	near term	low to moderate
	Logistics (e.g., reservation systems, fleet management systems)	low to moderate	nil	low to moderate	**moderate**	near term	low to moderate
	Traffic management (e.g., traffic controls, electronic road pricing)	**moderate**	nil	**moderate**	**moderate**	near term	low to moderate
	Advanced vehicle developments (e.g., automated vehicles)	low	**moderate**	nil	**moderate**	long term	low

Shaded cells indicate impact reduction potentials that are *moderate* or *high*.

* Non-renewable energy consumption includes non-renewable petroleum-based fuels.
** Other resources include those relating to the vehicle itself (e.g., materials), space requirements (e.g., land) and to the life-cycle use of the vehicle (e.g., waste).
† Air pollutants include CO, CO_2, NO_X, SO_2, lead, hydrocarbons, particulates and volatile organic compounds (noting that leaded fuel no longer is available in Canada but is available elsewhere).
†† Other impacts include health problems, traffic accidents, noise, vibrations, acid rain and global warming.

TABLE 4-4. SCREENING OF AIR MODE TECHNOLOGIES

TECHNOLOGY CATEGORY	TECHNOLOGY SUB-CATEGORY	IMPACT REDUCTION POTENTIAL				IMPLEMENTATION PERIOD	CURRENT CANADIAN R&D EFFORTS
		NON-RENEWABLE ENERGY CONSUMPTION*	OTHER RESOURCE CONSUMPTION**	AIR POLLUTION†	OTHER IMPACTS††		
Vehicle	Resource consumption (e.g., aerodynamics, materials, recycling)	**high**	low to moderate	low to moderate	low to moderate	near term	low to moderate
	Advanced vehicle developments (e.g., hydrogen-fuelled planes)	**high**	low to moderate	**moderate**	**moderate**	long term	low to moderate
Propulsion	Advanced engine developments	**moderate to high**	**moderate**	**moderate**	**moderate**	long term	low to moderate
Control	Information systems (e.g., travel information, navigation)	low to moderate	nil	low to moderate	**moderate**	near term	low
	Logistics (e.g., fleet management systems)	**moderate**	nil	low to moderate	low	near term	low
	Advanced vehicle developments	low	nil	nil	**moderate**	long term	low

Shaded cells indicate impact reduction potentials that are *moderate* or *high*.

* Non-renewable energy consumption includes non-renewable petroleum-based fuels.
** Other resources include those relating to the vehicle itself (e.g., materials), space requirements (e.g., land) and to the life-cycle use of the vehicle (e.g., waste).
† Air pollutants include CO, CO_2, NO_X, SO_2, lead, hydrocarbons, particulates and volatile organic compounds (noting that leaded fuel no longer is available in Canada but is available elsewhere).
†† Other impacts include health problems, traffic accidents, noise, vibrations, acid rain and global warming.

4.2 Screening Assessment Results

The following observations can be made about the results of Tables 4-1 through 4-4:

Overall results

- The three road sub-modes have almost ***identical*** results.

- The air mode results are ***similar*** to the road sub-modes, but apply to a smaller number of technology sub-categories.

Impact reduction potential

- For all three road sub-modes, **resource consumption** (vehicle category), **advanced vehicle developments** (vehicle category), **alternative fuel powered vehicles** (propulsion category), **advanced engine developments** (propulsion category), and **traffic management** (control category) have the **broadest potential** to **reduce** adverse impacts.

- In the case of the air mode, **advanced vehicle developments** (vehicle category) and **advanced engine developments** (propulsion category) have the **broadest potential** to **reduce** adverse impacts.

- For all three road sub-modes, the **potential reductions** in non-renewable energy consumption, other resource consumption, and air pollutant emissions of **alternative fuel powered vehicles** were ranked as **high**.

- For all three road sub-modes, **other impacts** could potentially be reduced by the **greatest** number of sub-categories (7 out of 10 sub-categories for large trucks and buses, and 6 out of 10 sub-categories for autos and small trucks). In the case of the air mode, **non-renewable energy consumption** and **other impacts** could both potentially be reduced by 4 out of 6 sub-categories.

The implications of the screening assessment results are:

- A subsequent detailed assessment of individual technologies (see Section 5.8) should focus on the following sub-categories: **resource consumption** (vehicle category), **advanced vehicle developments** (vehicle category), **alternative fuel powered vehicles** (propulsion category), **advanced engine developments** (propulsion category), and **traffic management** (control category). These sub-categories have the broadest potential to reduce adverse impacts; as well, current Canadian R&D efforts in these areas are low.

- A correlation should be made between the overall impact reduction potential of each environemental impact category (non-renewable energy consumption, other resource consumption, air pollution, and other impacts) and the "importance" of the category (which must be measured in terms of potential use, development cost, etc.).

Further observations can be made about the implementation period and Canadian R&D efforts, as follows:

- ***Implementation period:*** For all four modes and sub-modes, the implementation of ***advanced vehicle developments*** and ***advanced engine developments*** was estimated to occur in the ***long term***.

- ***R&D efforts:***
  Road sub-modes. Current Canadian R&D efforts are **mainly concentrated** on **alternative fuel powered vehicles** (propulsion category), as well as **advanced vehicle developments** (vehicle category) in the case of urban transit buses. The current Canadian R&D efforts in the areas of **resource consumption** (vehicle category), **advanced engine developments** (propulsion category) and **advanced vehicle developments** (control category) sub-categories which were estimated to have the broadest potential to reduce adverse impacts, are considered to be **low**.

  Air mode. Current Canadian R&D effort in the areas of **advanced vehicle developments** (vehicle category) and **advanced engine developments** (propulsion category) sub-categories which were estimated to have the broadest potential to reduce adverse impacts, are considered to be **low to moderate**.

As noted, the implementation period and Canadian R&D efforts were not used in the screening, but are used in Chapter 5 in the derivation of future directions.

5. DIRECTIONS

5.1 Overview

This chapter provides possible directions concerning the development and application of the screened technologies in sustainable transport. The directions represent potential roles for or actions by the federal government (TDC, Transport Canada and other federal agencies and ministries). They address means of further developing nascent technologies and commercializing technologies for widespread use, as well as ways of promoting the use of sustainable transport technologies as part of the SDS.

5.2 The Role of Technology in Sustainable Transport Policy

Section 1.3 showed that technology is one of three policy components of a sustainable transport strategy, the others being behavioural and fiscal policies. The discussion also showed that the three components are related, and that no single component will succeed in the absence of a coordinated effort among the three. As well, technologies can support sustainable transport policy because:

- Today's multi-modal transport systems are the products of technology; technological innovations contribute to their ongoing evolution.

- Society is open to technical fixes that do not require significant behavioural or fiscal changes. In other words, the travelling public tends to be more amenable to improvements that allow them to maintain current travel patterns and costs than to changing its behaviour, especially if these improvements appear to be transparent.

- By its nature, technological innovation can simplify or reduce the behavioural and fiscal changes that may be required to achieve sustainable transport goals.

Sustainable transport technology policies also must account for other government initiatives and for the realities of daily economic and environmental activities. They may, in fact, conflict with each other, as the following three examples demonstrate:

- ***Economic policies***, such as the deregulation of trucking and air travel, and the movement towards smaller, more frequent consignments, may generate a shift towards freight movement by road and air, which would increase further the adverse environmental impacts of these modes.

- ***Technological objectives*** sometimes conflict, or address one problem successfully at the expense of another. A notable example is the catalytic converter, which effectively eliminates some pollutants but increases fuel consumption and CO_2 emissions.

- ***The linkage of global and local impacts*** means, on the one hand, that localized actions may generate global impacts but, on the other hand, that global impacts may overwhelm local environmental improvements. One country may have more advanced environmental regulations than its neighbour, but the gains of the former may be obviated by the latter over a shared border.

Another conflict concerns two different policy directions. One implies improvements or refinements to existing transport technologies -- i.e., doing what we do today, but with less impacts. A second implies entirely new transport technologies (such as replacing internal combustion engines with fuel cells).

A review of the assessment of the four modes and sub-modes (Tables 4-1 through 4-4) suggests that the potentially most promising technologies fall under one or the other direction. The first direction maintains (but improves) current consumption patterns, while the second direction represents a complete changeover to new ways. Although both may require significant motivation in order to gain widespread adaptation, as noted above it has proven -- and likely will continue to be -- much easier to do so with the first group of technologies than with the second.

Both directions are appropriate to achieving sustainable transport goals. However, the two directions may be understood best in sequence, rather than as alternatives to each other. Improvements made to existing systems under the first direction may eventually give way to wholesale changes under the second direction, over time. At a certain point, decreasing rates of return should be expected to shift the focus from the first group to the second. This is because existing systems necessarily have practical limits beyond which they will be non-sustainable -- for example, internal combustion engines will always consume *some* fossil fuel and will always generate *some* air pollution, no matter how advanced the technologies.

This is perhaps most apparent for road modes (where most of the sustainable transport technology efforts have been concentrated historically). Table 2-2 showed that the greatest rates of improvement in auto energy consumption and pollution emissions took place prior to 1984. Subsequent improvements continue to show gains in reducing energy consumption and pollution, but at decreasing rates of return. For example, Table 5-1 shows savings in fuel consumption that are expected from current and near-term fuel technologies for heavy-duty trucks. (Some of the current technologies already have been introduced to the marketplace.) Collectively, these could decrease fuel consumption significantly; however, most of the projected individual savings are less than 10 percent. On the other hand, a package of relatively smaller scale initiatives may be more palatable, less costly and more easily accepted than one or two technologies that generate large savings in fuel consumption but which may require significant costs and changes in consumer behaviour to be successful. A package of initiatives also permits flexibility according to need.

TABLE 5-1. CURRENT AND NEAR-TERM HEAVY-DUTY VEHICLE FUEL-ECONOMY TECHNOLOGY*

TECHNOLOGY	PERCENT RANGE OF FUEL SAVINGS ESTIMATES
Current Technologies	
Diesel v. gasoline engine	30-55
Fan clutch	3-8
"Fuel-saver" diesel	5-20
- turbo charging	
- intercooling	
- low rpm	
- high torque rise	
Radial tires	3-10
Aerodynamic add-ons	3-10
- gap seals	
- side skirts	
- fairings	
- deflectors	
- air dams	
- boat tails	
- rounded corners	
- smoothed skin	
Tag axle	2-5
Improved lubricants	1-2
Near-Term Technologies	
Electronic controls	4
Aerodynamic design	5
Reduced empty weight	3
New generation tires	3
Reduced friction engine	7
Turbo compounding	8
Variable engine configuration	5
Turbine bottoming cycle	14

* *Source:* Graves, R.L., D.L. Greene and E.W. Gregory III, *Application of the Adiabatic Diesel to Heavy Trucks - A Technology Assessment*, Tables 2.1 and 2.2, prepared for Oak Ridge National Laboratory, 1986. Cited in D.L. Greene, *Transportation & Energy*, Eno Transportation Foundation, 1996, p. 143.

The sequential nature of the two directions is illustrated conceptually in Figure 5-1. The figure shows the actual, estimated and projected energy efficiencies for commercial aircraft, as measured by output (seat-miles per gallon). Technological innovations in commercial aircraft design, propulsion, etc., were targeted towards achieving a 67 percent increase in output (possible 100 percent) by about 2010. Replacement of *all* older commercial aircraft in the United States by existing (1990s) aircraft would improve output by 31 percent, from the 1989 level of 49 to 65 seat-miles per gallon. This represents the first direction, i.e., making the best of existing propulsion, vehicle and fuel technologies. However, expectations are that post-2000 advanced technologies (second direction) would improve fleet output by a further 55 percent[33]. These gains may be achieved by a mixture of existing technologies (first direction) and new technologies (second direction), marking the early part of the next century as a transitional time between the two directions.

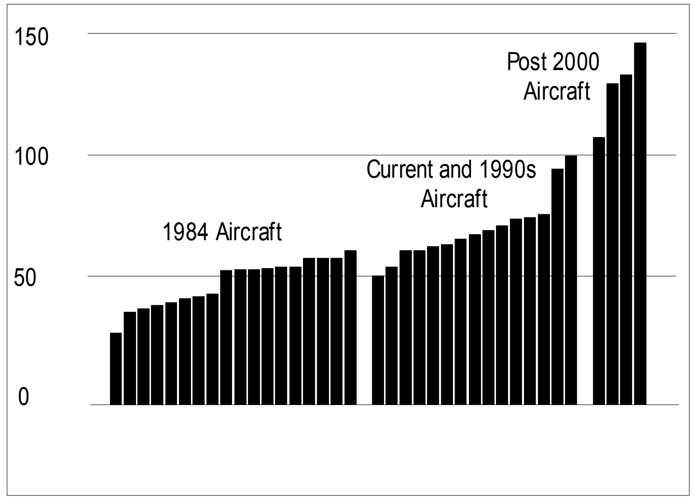

Figure 5-1. Commercial Aircraft Energy Effectiveness: Actual, Estimated, and Projected
Original source: Greene, D.L., 1992. "Energy – Efficiency Improvement Potential of Commercial Aircraft," Annual Review of Energy, vol. 17, pp. 537-573

5.3 The Role of the Federal Government

A key outcome of the preceding discussion is that a shift from the first group of technologies to the second is eventually likely, as returns from the first group diminish and as technologies in the second group come closer to achieving sustainable transport goals. This is illustrated conceptually by Figure 5-2 which suggests that current and near-term technological improvements eventually will generate limited improvements; whereas only the introduction of a new technology will achieve more ambitious benefits. The current and near-term technological improvements are representative of the first group of technologies; the long-term technological improvements, the second group. Furthermore, the second group is necessarily representative of higher levels of difficulty and costs than the first group.

An important role for the federal government will be to promote and encourage the shift to the second group of technologies at the appropriate time and with the appropriate policy and fiscal framework. In the meantime, technological development in both the first and second groups should be supported. Possible specific roles for the federal government in developing, supporting and promoting sustainable transport technologies, in both groups, include:

- Information broker;
- Marketing broker;
- Funding broker;
- Standards development;
- Employer policies;
- Policy development;
- Taxation and fiscal incentives.

These roles are described in Tables 5-2 to 5-8 (top part), respectively. In addition, the technological categories or sub-categories in which the federal government might play each role are identified, by a black dot, for all four modes and sub-modes (bottom part).

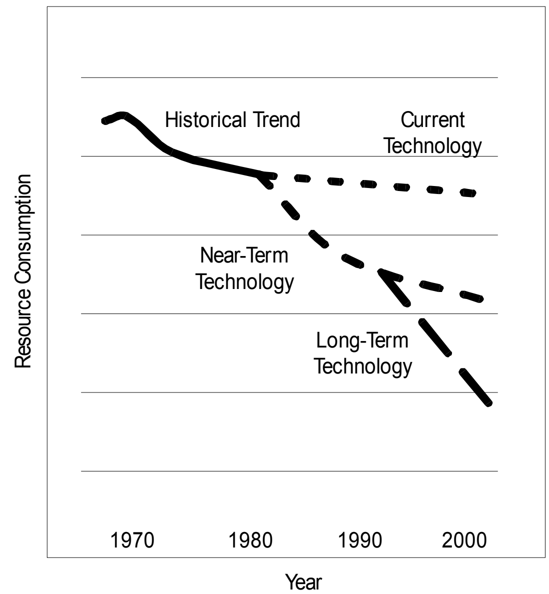

Figure 5-2. Conceptual Impact of Technology on Resource Consumption Over Time

TABLE 5-2. ROLE OF FEDERAL GOVERNMENT - INFORMATION BROKER

In this role, the federal government would serve as a central forum for the exchange of ideas, information and new developments in sustainable transport technologies. The forum would gather information from across Canada and around the world, and disseminate the information to other governments, agencies, regulators, carriers and the general public in Canada. The forum would monitor technological changes and R&D over time, as well as their implications to Canadian transport. The aim is to act as *the* Canadian voice on sustainable transport technologies.

Technology Category	Technology Sub-Category	Autos and Small Trucks	Large Trucks and Inter-city Buses	Urban Transit Buses	Air Mode
Vehicle	Resource consumption	●	●	●	
	Advanced vehicle developments	●	●	●	●
Propulsion	Alternative fuel powered vehicles	●	●	●	
	Advanced engine developments	●	●	●	●
	Exhaust after-treatment developments		●		
Control	Information systems	●	●	●	●
	Logistics		●	●	
	Traffic management	●	●	●	
	Advanced vehicle developments	●	●	●	●

Legend: ● Possible participation by the federal government

TABLE 5-3. ROLE OF FEDERAL GOVERNMENT - MARKETING BROKER

This role is similar to the Information broker role, but here the federal government would promote the use of sustainable transport technologies in all aspects of Canadian transport. This role also requires coordination with other federal SDS strategies, in order to ensure compatibility and to promote the use of technologies. Another key role is to "showcase" and promote Canadian sustainable technologies and applications around the world, with services ranging from providing the necessary offshore contacts and sponsoring international conferences, to funding promotional packages and on-site demonstrations.

Technology Category	Technology Sub-Category	Autos and Small Trucks	Large Trucks and Inter-city Buses	Urban Transit Buses	Air Mode
Vehicle	Resource consumption	●	●	●	
	Advanced vehicle developments	●	●	●	●
Propulsion	Alternative fuel powered vehicles	●	●	●	
	Advanced engine developments	●	●	●	●
	Exhaust after-treatment developments		●		
Control	Information systems	●	●	●	●
	Logistics		●	●	
	Traffic management	●	●	●	
	Advanced vehicle developments	●	●	●	●

Legend: ● Possible participation by the federal government

TABLE 5-4. ROLE OF FEDERAL GOVERNMENT - FUNDING BROKER

This role complements federal initiatives in funding research and development (such as NSERC grants in academia or, for example, the recent funds provided to further develop the Ballard Fuel Cell), with the federal government serving as a centralized location for linking potential funding partners and sponsors for sustainable transport technologies. These could include: the private sector; lending agencies; other federal ministries and agencies; provincial and municipal governments; transport carriers; public transit operators; transport manufacturers; academia; and transport / professional associations. Pilot demonstration projects, such as the federal government's co-sponsorship of demonstration natural gas urban transit buses, also would be treated in the same way.

The federal government also could use this role to establish partnerships with complementary technologies, such as the telecommunications / high-technology industries and the natural resource sector as well as other governments or agencies.

Technology Category	Technology Sub-Category	Autos and Small Trucks	Large Trucks and Inter-city Buses	Urban Transit Buses	Air Mode
Vehicle	Resource consumption	●	●	●	
	Advanced vehicle developments	●	●	●	
Propulsion	Alternative fuel powered vehicles				
	Advanced engine developments	●	●	●	●
	Exhaust after-treatment developments		●		
Control	Information systems				●
	Logistics		●	●	
	Traffic management	●	●	●	
	Advanced vehicle developments				

Legend: ● Possible participation by the federal government

TABLE 5-5. ROLE OF FEDERAL GOVERNMENT - STANDARD DEVELOPMENT

The federal government could develop standardized appropriate measures of sustainability as a means both of providing targets for Canadian technological developers and for identifying progress towards achieving SDS goals. This also would provide the federal government with a leading role in setting the "rules of the game", nationally and internationally.

Technology Category	Technology Sub-Category	Autos and Small Trucks	Large Trucks and Inter-city Buses	Urban Transit Buses	Air Mode
Vehicle	Resource consumption	●	●	●	
	Advanced vehicle developments	●	●	●	
Propulsion	Alternative fuel powered vehicles	●	●	●	
	Advanced engine developments	●	●	●	●
	Exhaust after-treatment developments		●		
Control	Information systems	●	●	●	●
	Logistics		●	●	
	Traffic management	●	●	●	
	Advanced vehicle developments	●	●	●	●

Legend: ● Possible participation by the federal government

TABLE 5-6. ROLE OF FEDERAL GOVERNMENT - EMPLOYER POLICIES

The federal government could introduce sustainable transport technologies into its own workplace, as a means of demonstrating their viability and field-testing new technologies or applications prior to widespread commercialization. The federal government has served in this role on previous occasions, for example, in promoting telecommuting.

Technology Category	Technology Sub-Category	Autos and Small Trucks	Large Trucks and Inter-city Buses	Urban Transit Buses	Air Mode
Vehicle	Resource consumption				
	Advanced vehicle developments				
Propulsion	Alternative fuel powered vehicles	●	●	●	
	Advanced engine developments				
	Exhaust after-treatment developments				
Control	Information systems				
	Logistics				
	Traffic management	●	●	●	
	Advanced vehicle developments				

Legend: ● Possible participation by the federal government

TABLE 5-7. ROLE OF FEDERAL GOVERNMENT - POLICY DEVELOPMENT

The federal government could develop prototypical policies and practices for other governments, carriers and other interests in the Canadian transport community, and could export these services to less developed countries. Within Canada, the federal government could play a coordinating role among federal, provincial and municipal governments and agencies.

Technology Category	Technology Sub-Category	Autos and Small Trucks	Large Trucks and Inter-city Buses	Urban Transit Buses	Air Mode
Vehicle	Resource consumption	●	●	●	●
	Advanced vehicle developments				
Propulsion	Alternative fuel powered vehicles	●	●	●	
	Advanced engine developments				●
	Exhaust after-treatment developments		●	●	
Control	Information systems				
	Logistics				
	Traffic management	●	●	●	
	Advanced vehicle developments	●	●	●	

Legend: ● Possible participation by the federal government

TABLE 5-8. ROLE OF FEDERAL GOVERNMENT - TAXATION AND FISCAL INCENTIVES

The federal government, in coordination with a large number of actors, could develop taxation and fiscal policies to develop, support and promote sustainable transportation technologies. Examples of such initiatives include tax credits for retro-fitting sustainable technologies in existing vehicles, or fuel tax rebates for the use of alternative fuels.

Technology Category	Technology Sub-Category	Autos and Small Trucks	Large Trucks and Inter-city Buses	Urban Transit Buses	Air Mode
Vehicle	Resource consumption	●	●	●	
	Advanced vehicle developments	●	●	●	
Propulsion	Alternative fuel powered vehicles	●	●	●	
	Advanced engine developments	●	●	●	●
	Exhaust after-treatment developments		●		
Control	Information systems				
	Logistics		●	●	
	Traffic management	●	●	●	
	Advanced vehicle developments				

Legend: ● Possible participation by the federal government

The preceding measures can be implemented by a large number of interests, including federal ministries and agencies, the provinces, private interests such as consultants and manufacturers, and universities, research groups and think tanks.

The federal ministries and agencies that could have a major role in supporting sustainable technologies are:

- Transport Canada
- Environment Canada
- Industry Canada
- Revenue Canada
- Transportation Safety Board
- National Transportation Agency
- NavCanada
- Canadian Airport Council
- Natural Resources Canada

5.4 Expert Review

An expert panel workshop was held with the Transportation Development Centre, in Montreal, on 27 January 1997. The workshop included external and internal specialists in sustainable transport, in order to provide a range of perspectives. The Consultant presented and discussed the study findings with the panel. The Study report incorporates the input and comments made by these panelists.

The panelists were:

C.G.B. (Kit) Mitchell, Transportation Development Centre visiting expert providing advice on sustainable transportation policy
Trevor Smith, Project Officer, at the Transportation Development Centre
Wayne Kauk, Acting Director, Sustainable Development, Programs and Divestiture, Transport Canada
Roberta Nichols, Consultant in alternative fuels
Robert Riley, Consultant in advanced vehicle technologies
Richard Soberman, Professor of Civil Engineering at the University of Toronto
Claude Guérette, the Transportation Development Centre's project manager on surface technologies
Michel Gravel, Delcan
David Kriger, Delcan

5.5 Internal Review

An internal panel workshop was held at Transport Canada's Ottawa offices on 1 April 1997. This workshop was comprised of internal specialists in sustainable transport, from TDC, Transport Canada and other federal ministries. This provided a range of perspectives among different federal government interests in sustainable development strategies. The consultant presented and discussed the study findings with the panel. The study report incorporates the input and comments made by these panelists.

5.6 Obstacles and Opportunities

Several complementary issues must be addressed so that the federal government can successfully develop, support and promote sustainable transport technologies. These represent both obstacles and opportunities. They include:

- Several federal departments, ministries and agencies are involved in discussing, developing, supporting and promoting sustainable transport and sustainable development. This coverage provides the necessary context for implementing sustainable transport technologies, and encourages input and feedback from a variety of perspectives. However, it also may result in overlapping responsibilities, research efforts, actions and resources, as well as the diffusion of responsibility among funding or sponsoring agencies (and, therefore, difficulty in moving specific actions forward).

- Data are lacking against which progress towards sustainability may be measured. The existing data are incomplete or inconsistent (temporal, spatial and modal coverage). Some information is out of date, and the quality and reliabiliy of other data may not be appropriate for the particular need at hand. The opportunity exists to complement other ongoing data collection efforts (by governments at all levels, intercity carriers, urban transit operators, industry associations, etc.). However, this requires a coordinated effort among data-gathering activities, including multiple sponsorship and funding of data collection activities. It may also require the development of new common standards for data exchange, manipulation and tabulation; here, opportunities exist for complementing existing data sets, GIS (geographic information system) data bases, etc., that are held among the various levels of government.

- The regulatory and fiscal roles of the federal government continue to evolve, as do the roles of other levels of government. At the same time, transport demand and supply continues to grow, without distinction by jurisdiction. Therefore, there is a need to coordinate the advancement of sustainable transport technologies as a national issue, in a way that is flexible (respecting the changing roles) and focuses upon the issue at all levels.

- A centralized, nation-wide coordinating mechanism or body is needed, in order to promote sustainable transport technologies. None exists today. This situation results again in the overlapping of efforts and the diffusion of responsibility within and among all levels of governments, as the implementation of sustainable transport technologies filters down to individual businesses and travellers.

- Mechanisms are required to permit, promote and/or implement partnering with various interests in sustainable transport technologies; namely, private sector interests, different levels of government, academia and research institutions.

- There is a need to move the sustainable transport technology issue higher on the political agenda at all levels. There also is a need to promote political and public awareness and the need for individual, corporate and public actions in the short term.

- The availability and allocation of funds from all sources -- governmental and private -- will continue to be a significant concern over the foreseeable future. This means that priorities must be set among sustainable transport technologies and among the actions that can be taken by the federal government, in order to advance the implementation of these technologies. (Section 5.7 addresses possible criteria for assessing these priorities.) It also means that alternative funding sources actively must be identified.

5.7 Detailed Assessment Criteria

TDC proposes to conduct a further detailed assessment of some or all of the screened technologies, as input to the development of Transport Canada's sustainable transport strategy. Although not used in this research, it is appropriate to propose criteria for this assessment here, in order to ensure consistency with the screening framework (see Section 4.1).

Some criteria are based upon a pass/fail or yes/no indication, while others use a ranking on a semantic scale. Acceptable "responses" may be yes, no, neutral or uncertain. The criteria define which environmental issues are to be addressed by the assessment framework, and the relative importance of these issues. The criteria also account for other issues -- for example, transport safety and efficiency -- in order to identify broader supporting or conflicting impacts of the technologies and the resultant effect on their applicability to sustainable transport.

The criteria are drawn from several sources, including the literature on sustainable transport technologies, Transport Canada definitions and the Transportation Association of Canada's (TAC) *New Vision for Canadian Transportation* and *Environmental Policy and Code of Ethics*[10]
However, many of these sources address the broader needs of sustainable transportation, as opposed to focusing on the technologies of sustainable transportation. An appropriate starting point can be derived from TDC's suggested working definition of a sustainable transportation technology, which

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[10] The *New Vision for Canadian Transportation* is set of 19 goals aimed at improving the efficiency and competitiveness of Canada's multi-modal transport system. The *Environmental Policy and Code of Ethics* is a statement of preferred and desirable practices in all facets of transport service provision, aimed at promoting environmentally-friendly practices. Both statements have been endorsed by Transport Canada, as well as other levels of governments, agencies and various operators.

is one that meets more than half the following conditions (see Section 1.2), and is repeated below for convenience:

> A technology ... that minimizes the overall negative impact of a transportation system; that improves safety; has a net economic benefit; improves access to all people, goods and services; involves public consultation; and reduces the consumption of non-renewable resources[3]

Several criteria are implied in this definition. These six criteria, plus one other (feasibility), are described in Table 5-9. The table constitutes the assessment framework for the *Sustainable Transport Technology: Framework for Action*. It lists and describes the criteria and their associated indicators. In many cases, the indicators are based upon measures of transportation system "outputs" or "performance", such as passenger-km or tonne-km of travel.

TABLE 5-9. ASSESSMENT FRAMEWORK

Sustainable Technology Goals Are To:	Criteria	Indicators (Measures)
Minimize overall negative impacts of a transport system	Pollutant emissions (including greenhouse gases, smog precursors, heavy metals, particulates, liquid wastes and solid wastes) Atmospheric loadings	Decreases pollutants generated / veh-km, psgr-km or tonne-km? Decreases concentration of pollutants?
Improve safety	Adverse impacts avoided due to fewer accidents	Reduces accidents, injuries or deaths / passenger-km or per tonne-km?
Have a net economic benefit	Production/operation/maintenance cost Equity Spatial Temporal	Positive benefit / cost ratio? Cost effective? Aggregate decrease in travel time, travel costs? Enlarges area of positive impacts? Demonstrates timely positive impacts?
Improve access to all people, goods and services	Productivity Accessibility to persons with disabilities	Increases GNP? Contributes to full accessibility?
Involve public consultation	Public acceptance	Does the public generally support the technology?
Reduce consumption of non-renewable resources	Energy consumption (non-renewable) Resource utilization during manufacture Usage of environmentally efficient *versus* non-efficient modes	Reduces fuel (litres) consumed / psgr-km, tonne-km, vehicle-km? Reduces tonnes consumed of non-renewable or environmentally sensitive raw materials / veh, psgr-km or tonne-km? Diverts psgr-km / tonne-km on efficient modes? Increases use and utilization of efficient modes?
Be feasible to implement	Status of research and application Availability to potential users	Proven commercial applicability (globally and in Canada specifically)? Cost geared to Canadian market? Barriers to implementation in Canada?

6. CONCLUSIONS

Chapter 6 concludes the research with a vision of a future with sustainable transport technologies, followed by a summary of key findings and recommendations.

6.1 Vision of the Future

It would be simplistic to describe technologies as being the panacea for sustainable transport. However, as this research demonstrates, there is a viable and critical role for technology in achieving any and all sustainable transport goals.

How might a vision of the future with sustainable transport technologies look? On one level, these technologies would reduce the consumption of non-renewable resources and minimize negative impacts (pollution). At a broader level, sustainable transport technologies could induce more sustainable urban form through, for example, the optimization of travel patterns (reduction in congestion). At a still broader level, these technologies could improve the general health and well-being of the population, which in turn has a positive net economic benefit on the nation's welfare.

The role, then, for a "framework for action" for sustainable transport technologies is to advance the development and diffusion of these technologies into common, every-day use.

6.2 Summary of Key Findings, Implications, and Responsibilities

The *Sustainable Transport Technology: Framework for Action* provides input to the development of Transport Canada's sustainable transport strategy. The Minister of Transport's Sustainable Development Strategy (SDS), which incorporates both internal stewardship activities and those that involve the transport sector at large, must be tabled in Parliament by December 1997.

The *Sustainable Transport Technology: Framework for Action:*

- ***Identifies and categorizes candidate technologies*** that potentially can support sustainable transport.

- ***Assesses and screens these technologies***, for subsequent detailed evaluation by Transport Canada concerning their potential in a sustainable transport strategy for Canada, as input to the SDS.

- ***Gives direction*** concerning the applicability of the screened technologies, and the Federal Government's role in supporting these technologies.

- ***Develops meaningful and practical criteria*** for subsequent evaluation of the potential of the technologies.

Four key products may be said to constitute the main results of the *Sustainable Transport Technology: Framework for Action*.

The first important product of this research is the preparation of an *inventory* of sustainable transport technologies. This was achieved in the form of a detailed listing and description of candidate technologies.

A second product is the *categorization* of these technologies, according to technology, mode and impact potential. This categorization allows the technologies to be compared and assessed in a systematic and consistent manner, according to a common basis. Accompanying the categorization is a set of evaluation criteria for subsequent detailed assessment of the technologies.

Taken together, these two products yielded the sustainable transport technology sub-categories that offered the broadest potential to reduce adverse impacts. These are: **resource consumption** *(vehicle category)*, **advanced vehicle developments** *(vehicle category)*, **alternative fuel powered vehicles** *(propulsion category)*, **advanced engine developments** *(propulsion category)*, and **traffic management** *(control category)*. The subsequent detailed assessment of individual technologies should focus upon these sub-categories.

Perhaps most important is a third product; namely, two policy directions for achieving sustainable transport goals. The first direction implies improvements or refinements to existing transport technologies and maintains (but improves) current consumption patterns. The second direction implies entirely new transport technologies and therefore represents a complete changeover to new ways.

The two directions may be seen more appropriately in sequence, rather than separately. This is because, as discussed in the research, a shift from the first group of technologies to the second is eventually likely, as returns from the first group diminish and as technologies in the second group come closer to achieving sustainable transport goals. In other words, current and near-term technological improvements eventually will generate limited improvements; whereas only the introduction of a new technology will achieve more ambitious benefits. The current and near-term technological improvements are representative of the first group of technologies; the long-term technological improvements, the second group. Furthermore, the second group is necessarily representative of higher levels of difficulty and costs than the first group.

A fourth principal product is the identification of roles or actions by the Federal Government, intended to develop, apply and promote sustainable transport technologies along the aforementioned directions. Seven such roles and actions are identified, and are summarized below:

1. *Information brokers* -- serve as a central forum for the exchange of ideas, information and new developments in sustainable transportation technologies.

2. *Marketing broker* -- promote the use of sustainable transport technologies and applications in all aspects of transport in Canada and around the world.

3. *Funding broker* -- actively promote and link potential funding partners and sponsors for sustainable transport technologies.

4. *Standards development* -- develop appropriate standardized measures of sustainability as a means of providing targets for Canadian technological developers, and identifying progress towards achieving SDS goals.

5. *Employer policies* -- demonstrate the viability of sustainable transport technologies, and field-test new technologies or applications prior to widespread commercialization.

6. *Policy development* -- develop prototypical policies and practices, export these services to less develop countries, and coordinate efforts among Federal, provincial and municipal governments and agencies.

7. *Taxation and fiscal incentives* -- develop taxation and fiscal policies to develop, support and promote sustainable transportation technologies.

An additional and important role for the Federal Government would be to promote and encourage the shift from the first group of technologies to the second, at the appropriate time and with the appropriate policy and fiscal framework.

6.3 Recommendations/Next Steps

Products three (policy directions) and four (roles for the Federal government) constitute the primary recommendations of the research.

A recommended first step towards implementing these products is the detailed assessment of candidate technologies, with the aforementioned criteria providing the evaluation framework.

An important second step would be an action plan that details the implementation of the recommended policy directions and roles in Transport Canada and other Federal departments and agencies, and establishes the mechanisms for broad, cooperative efforts with other governments, other public agencies, the private sector, academia and research institutions.

However, the implementation of any specific action by the providers of transport services and/or the Federal Government requires a coordinated and supportive effort among the three policy groups mentioned in Chapter 1; namely, behavioural, fiscal and technological policies. This recognizes that none of the three policy groups alone can achieve sustainable transport goals. Nor is technology a panacea for all of society's problems. A coordinated effort will be required to achieve progress towards sustainability in transport. In turn, this requires that the obstacles and opportunities identified in Section 5.7 be addressed, which would result in a coordinated, nation-wide effort that will go far towards achieving sustainable transport goals. Finally, much depends upon guiding, or providing the appropriate conditions for, general acceptance and use of sustainable transport technologies by the travelling public.

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