

ENERGY AND TRANSPORT FUTURES

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Relative to demand, oil is no longer in plentiful supply. The time when we could count on cheap oil and even cheaper natural gas is clearly ending.

DAVID O'REILLY, Chairman and CEO, ChevronTexaco Corp
Cambridge Energy Research Associates conference
Houston, Texas, February 15, 2005

The world contains abundant oil resources to meet demand for decades to come.

MICHAEL C. LYNCH, Consultant affiliated with Massachusetts Institute of Technology
Article in the *Globe and Mail*, May 28, 2005

In mid-2004, [Saudi Arabia] was the only country in the world with an appreciable amount of sustainable capacity in reserve.

World Energy Outlook 2004
International Energy Agency, Paris, France, 2004

Absent a series of new giant oilfield discoveries, or a new technology that causes difficult oil now being left behind to flow readily into prolific high-recovery wells, Saudi Arabia seems clearly to be nearing or at its peak output and cannot materially grow its oil production.

MATTHEW SIMMONS, Chairman and CEO, Simmons & Company International
Twilight in the Desert: The Coming Saudi Oil Shock and the World Economy,
Wiley, New York, 2005

There is now a great deal of scientific evidence showing nuclear power to be an environmentally sound and safe choice. ... [It] offers an important and practical pathway to the proposed 'hydrogen economy'. ... A hydrogen fuel cell-powered transport fleet would not only virtually eliminate CO2 emissions but would eliminate the energy security problem posed by reliance on oil from overseas.

PATRICK MOORE, Greenpeace founder; Chair, Greenspirit Strategies Inc.
Statement to the Subcommittee on Energy & Resources
U.S. Congress, April 28, 2005

Hydrogen cannot win the fight against its own energy source. Therefore, the answer to the question: 'Does a Hydrogen Economy Make Sense?' is an unconditional 'NEVER'. A global hydrogen economy has no past, present or future!

ULF BOSSEL, Fuel cell consultant, Oberrohrdorf, Switzerland
European Fuel Cell Forum, Lucerne Switzerland, July 4-8, 2005

At a meeting of the Electric Vehicle Association in February 1913, one member predicted a "golden harvest for electric vehicle manufacturers" because of the rise of oil from 65¢ to \$2.35 a barrel since the turn of the century.

RICHARD SCHALLENBERG
Prospects for the Electric Vehicle: A Historical Perspective
IEEE Transactions on Education, vol. E-23, No 3, August 1980

Summary

This paper sets the stage for a look at the energy and transport aspects of Canada's future until about 2031. The focuses are on oil, whose products fuel almost 100 per cent of transport in Canada, and on road transport, responsible for consumption of almost 80 per cent of the oil products used for transport. Other motorized modes—rail, marine, air—are also discussed, and other transport fuels, notably electricity and hydrogen.

The paper provides a brief and reasonably balanced appraisal of each transport mode and fuel opportunity and includes original analyses of several factors in past and potential transport activity and related energy use.

The central consideration in the paper is that humankind is approaching the beginning of the end of an era of low-cost petroleum availability. The era will end when oil production is unable to keep up with demand for oil, rather than when oil is exhausted. Petroleum availability will continue, but it will become progressively more expensive and increasingly susceptible to replacement by other fuels. Some of these fuels will enable continued use of internal combustion engines. Others fuels will be more suitable for generation of electricity, including a wide range of renewable fuels.

Partly impelled by prospects of fuel availability, but also by recognition of other advantages, industrialized societies are also at the beginning of another era involving—for land-based modes at least—a transition from the internal combustion engine to the electric motor. This transition could be slow, because there is a large potential for reducing fuel use by internal combustion engines.

Eventually, perhaps by 2031, most transport will have electric motors. What is less clear is how the electricity will reach the motors. Much of the automotive industry and many governments favour the eventual deployment of hydrogen fuel cells. The authors do not share this enthusiasm, in large part because producing electricity from hydrogen that has been made from electricity is inefficient and thus inappropriate for an era of energy constraints.

The authors foresee greater reliance on tethered (grid-connected) vehicles, i.e., vehicles to which electricity is delivered continuously via a wire or rail, because such vehicles offer the best opportunities for convenient and effective transport on land when energy is scarce and mostly secured from renewable sources.

The authors foresee too that marine transport will make more use of wind, and much better use of liquid fuels. Aviation will decline, because it is inherently fuel intensive and because there are no cost effective replacements for present oil-based aviation fuels.

The authors' main message, however, is not that these outcomes are certain but that there major risks in attempting to deny that they are possible and continue with 'business as usual.' Numerous energy and transport scenarios should be explored, with rigour and urgency.

Chapter 1. Introduction

Humans have developed ways of living that depend on continuous inputs of large amounts of added energy, almost all in the form of fossil fuels: oil, natural gas, and coal. These inputs fuel our vehicles, heat and cool our buildings, power our technology, enhance our agriculture, and make possible every aspect of our extraordinary industrial activity. The same resources—oil, gas, coal—are essential feedstocks for many of industry's products, including plastics, fertilizers, and pharmaceuticals. The added energy has supported a growing world population that in turn makes use of ever-increasing amounts of the fossil fuels. Amounts used per capita grow as affluence spreads, even though some of this growth is offset by more efficient use.

The continuous growth in fossil fuel use that characterizes and supports human endeavour is challenged on two fronts. The first arises from the understanding that some of the by-products of this use are accumulating in ways that drastically alter the ecosystems that support human existence.^{1†} Among the best-known of such by-products are greenhouse gases (GHGs) that trap the sun's heat and thereby affect the earth's climate. Avoidance of unacceptable climate change will require reductions—perhaps drastic reductions²—from present levels of fossil fuel use.

The second challenge arises from the finite nature of fossil fuels and how they are distributed within the earth's crust. There are limits to the rate at which they can be extracted and, eventually, how much can be extracted. The first limit is in sight in the case of oil. Production is beginning to fail to keep up with demand,³ with the prospect of ever-higher oil prices as supply declines, potential demand increases, and the gap between the two widens. A production limit is also evident for natural gas from North American wells, although worldwide such a limit appears to be a few decades away. Limits on coal production, in North America and worldwide, are less imminent and may be many decades ahead.

On the face of it, the production limits could solve the emissions problem or at least contribute to the solution, especially when production begins to decline. A fall in production could result in some or all of the reductions in fossil fuel use required to reduce the threat of climate change. We may not have to take special action to reverse the growth in fossil fuel use and GHG emissions, it could be argued, because such a reversal is going to happen anyway.

There are at least two kinds of problem with such a wait-and-see position:

- The timing and extent of the production limits may not be such as to avert catastrophic change in climate. Moreover, a consequence of limited oil production could, for example, be increased use of coal, which would exacerbate the emissions problems.
- A particular aspect of humanity's energy dependence is its reliance on elaborate, energy-hungry transport arrangements, powered almost entirely by internal combustion

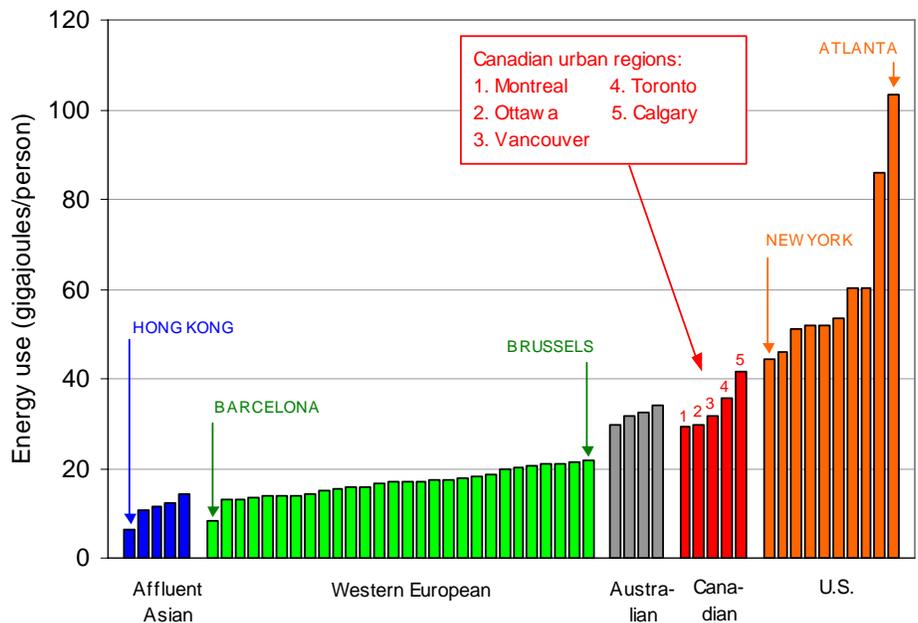
[†] Superscript numbers point to 280 numbered notes on Pages 65-96 that provide sources of information, including sources for material in boxes, and additional analysis and commentary.

engines (ICEs) and jet engines fuelled by oil products. Major parts of human activity comprise movement by motorized transport, which shapes settlement patterns, social arrangements, and economic activity. Transport facilitates much industrial and commercial activity, allows widespread use of the results of this activity, and removes the residues of the use. There is no ready substitute for the oil-fuelled transport systems that underpin most aspects of everyday life and support the globalized economy. Rising oil prices may be an insufficient stimulus for timely development of adequate alternative arrangements. The result could be continued dependence for transport on ICEs and jet engines, and oil to fuel them, but at a cost high enough to cause severe economic and social dislocation.

This paper is concerned primarily with the second kind of problem, specifically with **how effective transport arrangements might be sustained in Canada if oil supplies were to become constrained**. It also addresses the first kind of problem by showing ways in which fossil fuel use by Canada's transport sector could be substantially reduced, thereby contributing to efforts to minimize harmful accumulation of GHGs and several other, toxic pollutants.

Because of Canada's vast size and extensive international trade, the transport sector contributes more than in most countries to maintaining a high standard of living. Trade comprises a higher proportion of Canada's GDP than that of any other G8 country.⁴ Canada's urban and other settlements are more widely scattered than in any other affluent country. Without effective and efficient transport services, the lives of most Canadians would be significantly impoverished.

Box 1. Energy use for passenger transport in 52 affluent urban regions, 1995



Source: Kenworthy and Laube (UITP)

On the other hand, as illustrated in Box 1,⁵ residents of Canada's largest urban regions use considerably less energy for transport within their regions than residents of large U.S. urban regions, although much more than residents of urban regions in Europe and Japan. Also, Canada is one of only two current net oil exporters among G8 countries, and the only one that seems likely to be producing more oil than it is consuming in 2030.⁶

Canada thus faces a distinctive mix of challenges and opportunities in adapting to an oil-constrained world, circumstances that will call for a distinctly Canadian solution that cannot simply be copied from innovations in other affluent industrial nations.

The balance of this report lays out our predicament and begins a discussion of our options. Chapter 2 describes transport technologies and options. Chapter 3 discusses the prospective availability of fuels for ICEs and jet engines, which today power almost all transport, taking both global and Canadian perspectives. Chapter 4 similarly discusses fuels for electric drives, which offer the most developed alternative technology for powering most surface transport. Chapter 5 touches on some social and economic drivers of transport activity.

Chapter 6 provides some concluding remarks by opening a discussion as to whether and how Canada, facing a distinctive set of challenges, might achieve a 'soft landing' rather than a 'hard landing' in response to the transport turbulence that lies ahead. Developing solutions that can make the most of Canada's energy and transport futures will require ambitious thinking on the part of government and industry, going far beyond attempts that have been made in this direction to date. Such a project warrants the levels of dedication and effort being devoted to meeting Canada's Kyoto Protocol commitment, and would make a strong contribution towards meeting that commitment.

The goals of this paper are to raise issues and stimulate discussion rather than resolve the challenges that are highlighted. No answers are provided and few conclusions are drawn. Our overall aim is to illustrate the need for substantial work on Canada's transport and energy futures. This work could involve the setting of goals, the elaboration of alternative ways of meeting the goals, and the development of policies that help make sure preferred routes are taken. It should certainly involve more thorough analysis of the issues we discuss here, which are often given only cursory treatment.

Chapter 2. Transport technologies

2.1. Fuels or vehicles first?

The primary purpose of this report is to discuss trends in energy availability that could influence the development of Canada's transport systems until 2030. Analyzing such alternatives is challenging because of the interdependent relationship between fuels and vehicle propulsion technologies. Logically, discussion of fuels should come first, because without fuels vehicles cannot run. However, neither can be discussed without reference to the other, and we have opted to begin with discussion of vehicles that takes account of fuel sources. This initial focus makes it easier to understand what might happen to transport over the next few decades. But what *will* happen will depend more the availability of oil, discussed in Chapter 3, than on any other single factor.

Because we are beginning with a discussion of vehicles, the reader might well gain the impression that we believe that future transport challenges will be amenable to technological fixes that allow Canadians to move themselves and their goods in much the same way as they have done since the 1960s. This would be a false impression. We believe that radical changes in transport activity are necessary and likely to occur before 2031. We think there will be a substantial moderation of what has been described as our 'hyper-mobility',⁷ in the movement of both people and freight. How this moderation might occur is touched on here, chiefly in Chapter 6, but it warrants much more focussed analysis.

2.2. Internal combustion engines (ICEs) vs. electric drives

A few thousand automobiles were produced in North America in 1900. Of these, about half were steam-driven adaptations of the rail locomotives that had revolutionized transport during the previous six decades. The steam-powered automobiles were powerful, with good acceleration, and could burn a variety of fuels. However, they were hard to start, taking some minutes to get up steam, hard to drive, and hard to maintain. About a third of the total were battery-powered electric vehicles. They were very easy to start and to drive, but were slow and could not stray too far from the few recharging opportunities. The remaining sixth were powered by gasoline-fuelled internal combustion engines (ICEs), which were noisy, smelly, and polluting, but whose qualities were somewhere in between the more popular steam- and electric-powered vehicles.⁸

Visionaries, notably Thomas Edison, believed the future belonged to electric-powered vehicles, but ICE-vehicles, perhaps the second-best solution, became the overwhelmingly dominant transport technology during the 20th century. Electric vehicles' main drawback was and remains the low power density of batteries and other storage devices for electricity. (Power density is the amount of energy stored per kilogram of weight. Low power density in a battery means little power, a short range, and frequent recharging.) Edison spent the equivalent in today's dollars of some US\$22 million of his own funds trying to develop a better battery.⁹ This work tripled the power density to about the current value for lead-acid batteries but the result was far short of the effective power density of gasoline, which is at least 100 times greater.¹⁰

Today's best batteries have power densities of up to six times that of lead-acid batteries, but they are much more costly, and still fall far short of gasoline and diesel fuel as an energy source for vehicles.¹¹

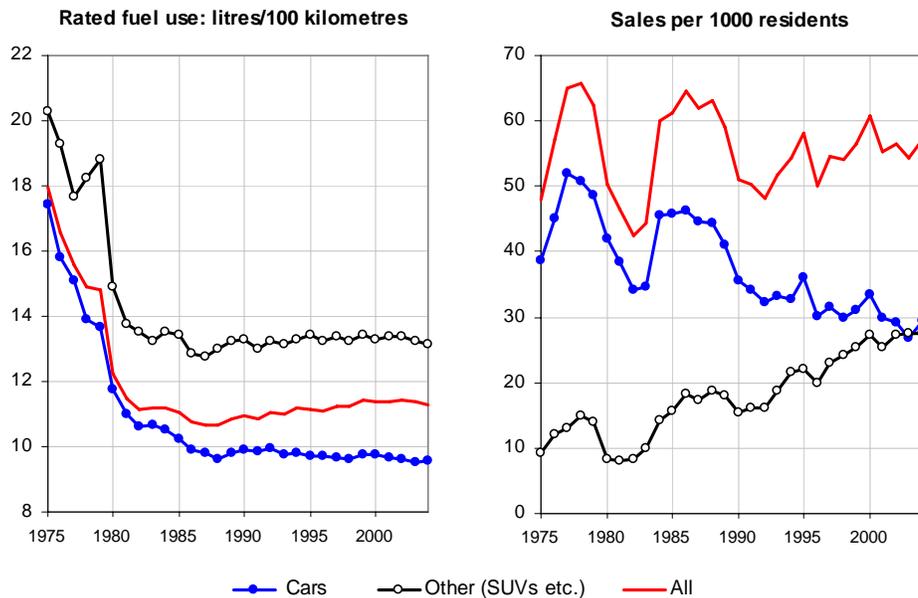
Nevertheless, the advantages of electric vehicles remain. They are quiet, powerful, light in weight (except for the battery), and pollution-free at the vehicle. They are making a comeback in ways that require less reliance on batteries and other storage devices. Indeed, the two main automotive questions for the next few decades are (i) how much of an inroad will electric vehicles make against pure ICE-based vehicles; and (ii) which kind of electric vehicle will predominate? For the second question, there are three main contenders, as will be detailed below: vehicles with hybrid electric-ICE drives, vehicles with fuel cell drives, and tethered vehicles that get their electric power while they are moving from a nearby rail or wire. Battery-powered electric vehicles will also have brief further discussion.

2.3. ICEs have a lot of life in them

In Canada and the U.S., more than 97 per cent of motorized transport is fuelled by oil products,¹² and almost all of this is used in ICEs.¹³ (Oil used for transport comprises 71 per cent of end-use consumption of oil,¹⁴ with the remainder shared roughly equally between industry, including use as a chemical feedstock, and electricity generation.)

As will be demonstrated in Chapter 3, it's likely that during the next few decades, perhaps during the next few years, there will be major constraints on the availability of oil. These

Box 2. Rated fuel use of light-duty vehicles sold in the U.S. (left panel) and sales per capita (right panel), 1975-2004 model years



Source: U.S. Environmental Protection Agency

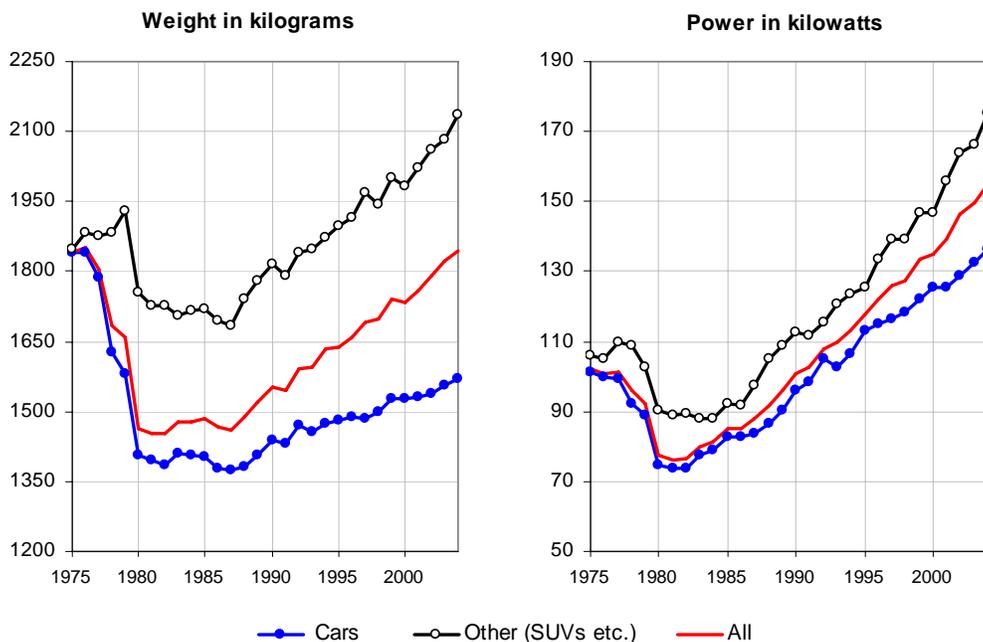
constraints could drive the price of fuel for ICEs to several times today’s prices. However, there’s much scope for improving the efficiency with which oil is used for transport, and thereby greatly reducing the impact of such price increases.

For example, new regular automobiles in the U.S.—i.e., not minivans, SUVs or pick-up trucks—presently have an average fuel use of about 9.6 litres per 100 kilometres (see the lowest plot in the left-hand panel of Box 2).¹⁵ This compares with averages of 6.4 and 5.2 L/100 km for cars sold in Europe and Japan respectively.¹⁶

The case is often made that heavier and more powerful cars are needed for North American conditions, but if there is such a need it is relatively new. The plots of weight and power in Box 3 show that 2004 model-year cars were 14 per cent heavier and 58 per cent more powerful than cars sold in 1988.¹⁷ Car manufacturers achieved these increases without raising rated fuel consumption (Box 2). If the same technological improvements had been used instead to improve fuel economy rather than boost weight and power, new cars today would use 21 per cent less fuel, i.e., 7.5 rather than 9.6 L/100km, i.e. approaching the European level.¹⁸

The previous two paragraphs concern regular cars. There has been a remarkable change in the kind of vehicles driven by North Americans for personal transport over the last three decades, illustrated for the U.S. in the right-hand panel of Box 2. The share of sales of vehicles known collectively as ‘light trucks’—which include small passenger vans, sport-utility vehicles, and pick-up trucks—has risen from about 20 per cent to about 50

Box 3. Weighted average vehicle weight (left panel) and engine power (right panel), light-duty vehicles sold in the United States, 1975-2004 model years



Source: U.S. Environmental Protection Agency

per cent. The surge in light-truck use is particularly evident in North America compared with elsewhere because fuel prices are low and because light trucks are favoured by regulations and agreements that limit fuel consumption.¹⁹

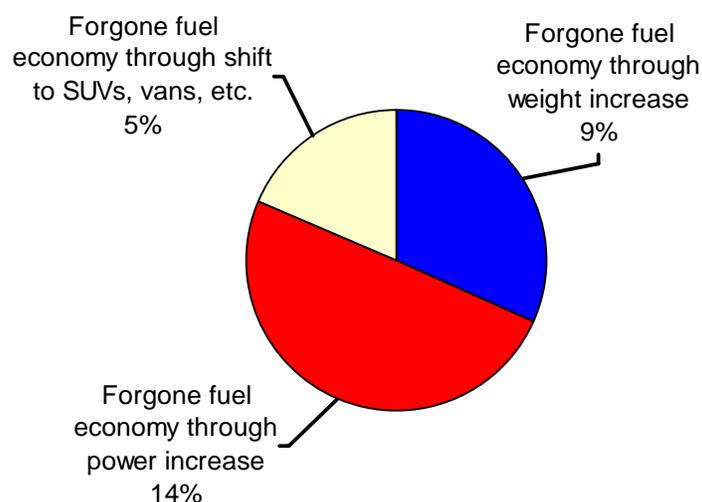
Light trucks are heavier and more powerful than regular cars, and have become relatively more so over the years compared with regular cars (see Box 3). The increases in light trucks' power and weight have also been introduced without increasing fuel consumption (Box 2).²⁰ As was done above for regular cars, it's possible to estimate what would be the fuel use of these light trucks if the technological improvements since 1988 had been used to improve fuel economy for this class of vehicles rather than increase power and weight. In this case, the reduction in fuel use would have been even greater: 27 per cent, vs. the noted 21 per cent for cars. The combined reduction for cars and trucks would have been 24 per cent.

It's also possible to estimate the effect of the shift to light trucks alone, i.e., if the increases in power and weight had not happened. Overall, the total forgone fuel savings is 28 per cent. How this is disaggregated among the three factors—increased weight, increased power, shift to light trucks—in combination is shown in Box 4.²¹

Thus, considerable savings in fuel use could have been achieved if one or more of three things had *not* happened: (i) increases in vehicle weight; (ii) increases in vehicle power; and (c) increases in the share of light trucks among personal vehicles sold each year. A possibly surprising finding, clear from Box 4, is that the shift to SUVs and other light trucks has made the *smallest* contribution to total forgone fuel economy. Increases in the average weight and particularly power of *all* kinds of vehicles have both made larger contributions. Nevertheless, it's the growth in the use of SUVs that has received the publicity.

Also, among the vehicles classified as light trucks, SUVs are the smallest of the three categories. In 2003, these vehicles comprised 37 per cent of registered light-duty vehicles

Box 4. Components of 28 per cent forgone fuel economy, 1998-2004



in Canada. These included pick-up trucks (16 per cent of the total), vans (13 per cent), and SUVs (8 per cent). SUVs had been growing in number at a higher rate than the other categories (a 29-per-cent increase between 2000 and 2003 vs. six per cent for regular cars) but they remained a minor category, even among light trucks.²²

How quickly could things change? A feature of the data in the left-hand panel of Box 2 is the remarkable change in fuel economy that occurred between the 1975 and 1980 models, when rated new-vehicle fuel use per 100 kilometres fell by 31 per cent in five years. It fell another 13 per cent during the next eight years. The right-hand panel of Box 2 shows that these major efficiency improvements did not deter sales; indeed, sales were higher per capita in most of those years than in 2004.

An important barrier to reducing fuel use through technology improvements is the turnover of the vehicle fleet. At current replacement rates, seven years would be required to replace half the light-duty vehicles on the road in Canada and 12 years to replace three quarters of the total.²³ Turnover could be accelerated by an incentive program,²⁴ although if a replacement vehicle were not to have at least 15-per-cent better fuel efficiency than what it replaces there could be a net increase in energy consumption, resulting from the additional energy used during vehicle manufacture.²⁵ Acceleration of turnover would counteract an apparent trend for vehicles to last longer.²⁶

Implement of an effective incentive program that favoured smaller, lighter vehicles could mean that by 2020 personal vehicles on the road in Canada would each use on average only half to two thirds of their current oil use.²⁷ Further economy could be achieved by a switch to diesel engines for personal vehicles, as is commonplace in Europe, which could more than offset growth in the number of vehicles on the road.²⁸ Thus, continued use of ICE vehicles, using currently available technology, could reduce oil use for this purpose by as much as half by 2020, even allowing for some increase in the number of vehicles on the road.

Whether such changes would be enough to keep ICE vehicles on the road through 2020 and beyond to 2031 remains to be seen. The potential for them does suggest that the ICE could continue to be a favoured technology for personal vehicles for many years ahead, providing stiff competition for alternative propulsion technologies such as those discussed below.

2.4. MOU on GHGs between the auto industry and the federal government

After Section 2.3 was written, the Government of Canada announced the signing of a Memorandum of Understanding with the automobile industry that, on the face of it, could commit the industry to extraordinarily ambitious reductions in fuel use by 2010.²⁹ The companies have undertaken to reduce by 2010 GHG emissions from light-duty vehicles *in operation*—cars, SUVs, vans, and pick-up trucks—to 5.3 megatonnes (Mt) below a ‘reference case’ for 2010, deemed in the MOU to be 90.51 Mt.³⁰

Box 5. Federal government estimates of GHG emissions from light-duty vehicles, together with projected emissions and required reductions in fuel consumption

	<i>Outlook</i>	<i>Database</i>	<i>Inventory</i>
GHG emissions from all light-duty vehicles on the road in megatonnes in:			
1990	72.3	74.2	75.5
1995	77.4	76.9	79.8
2000	82.3	81.9	85.9
2005	85.2	88.0	93.4
2010	90.5	93.3	100.0
MOU target for 2010 in megatonnes	85.2	85.2	85.2
Per-cent reduction from 2010 projection required to meet MOU target for 2010	5.9%	8.7%	14.8%
Estimated per-cent reduction in average fuel consumption by 2010 new vehicles	25%	35%	60%

The target is thus to have total GHG emissions from all light-duty vehicles on the road at or below 85.2 Mt.

To assess the scale of what the automotive industry has to do to comply with the MOU, it's necessary to know the current level of emissions from these vehicles, and where it is heading for 2010. Confusingly, the federal government offers three estimates relevant to these levels!

The three sets of estimates are laid out in Box 5. '*Outlook*' refers to a document produced by Natural Resources Canada in 1999.³¹ It is now of historical interest only, *except* that it is the document used in the MOU to define the reference case. '*Database*' refers to an online resource provided by Natural Resources Canada that provides estimates of GHG emissions for each year from 1990 to 2002.³² '*Inventory*', a document published in 2004 by Environment Canada, provides a different set of estimates of GHG emissions for these 13 years.³³ '*Inventory*' contains Canada's 'official' estimates. These are the estimates of GHG emissions that Canada prepares and submits annually as part of its obligations as a signatory to the United Nations Framework Convention on Climate Change.

The projections for 2000-2010 in Box 5 under the column '*Outlook*' are in that document. The projections for 2005-2010 under the columns '*Database*' and '*Inventory*' are those of The Centre, based on straightforward extrapolation from the estimates in those sources.³⁴

The third to last row of the table in Box 5 shows the target set out in the MOU as applying to each emissions projection. Logically, it might be thought of as applying only to the *Outlook* projection, but that is clearly out of date. According to Canada's official reporting—in the *Inventory* document—emissions from light-duty vehicles already totalled 91.1 Mt in 2002, and were rising.³⁵ The projection that may be conceptually the closest to that of the *Outlook* could be that based on the more up-to-date estimates in the *Database*.

However, if a different project from that in the *Outlook* is to be used, one based on the estimates in the *Inventory* may have the most validity.

The last row of the table shows required reductions in average fuel consumption by 2010 model-year vehicles for each of the reductions indicated in the next-to-last row. The critical assumptions in estimating these reductions were: (i) all of the required reductions by light-duty vehicles on the road will have to come from efficiency improvements to new vehicles,³⁶ (ii) about 50 per cent of the fleet will change over between 2005 and 2010,³⁷ (iii) cars sold during these years will perform about 50 per cent of the kilometres in 2010,³⁸ and (iv) the reductions will be phased in.³⁹

Given that the average fuel consumption of light-duty vehicles sold in Canada fell by only about seven per cent between 1990 and 2002,⁴⁰ a reduction by 25 per cent between 2005 and 2010 would be remarkable. A reduction by 60 per cent would be extraordinary.

For the 2005 model year, the average rated fuel use was likely close to nine litres per 100 kilometres (L/100 km).⁴¹ A 60-per-cent reduction would mean reducing the average for 2010 to below four L/100 km by 2010. This will be an undertaking without precedent. Historically, the largest reduction achieved in a five-year period was 38 per cent, from 18.0 to 12.3 L/100 km between 1975 and 1980.⁴²

To put this in context, only one of the approximately 980 types of model-year 2005 light-duty vehicles rated by the federal government achieve less than four L/100 km, only four more achieve less than five L/100 km, and only 14 more achieve less than seven L/100 km.⁴³ (The last level corresponds to an approximate 25-per-cent reduction from the 2005 average.)

Implementation of the MOU at even the minimal indicated level—i.e., a 25-per-cent-reduction in average fuel consumption by model year 2010 light-duty vehicles—would represent a major step towards transport sustainability, especially if fuel prices rise thereby reducing the possibility of increased fuel use resulting from reduced costs of vehicle operation.⁴⁴

There are two wrinkles in the path to implementation of the MOU. One is that the agreement is voluntary,⁴⁵ and Canadian industry's adherence to voluntary agreements is mixed.⁴⁶ The other is that the accord allows for adjustments to the 'reference case'. For example, the reference case could be changed to one of the 2010 projections in Box 5 other than the one specified in the MOU (i.e., to the 2010 projections in the *Database* or *Inventory* columns rather than the one in the *Outlook* column). This would have the effect of reducing the required reduction in GHG emissions and thus the required improvement in fuel economy. Indeed, if the reference case were raised to about 105 Mt, no special action on the part of the auto industry might be required.

A government-industry committee will determine whether a target has been reached after May 31 in the year following the model year, i.e., after May 31, 2011 in the case of model-year 2010 vehicles, using industry and government estimates of GHG emissions.

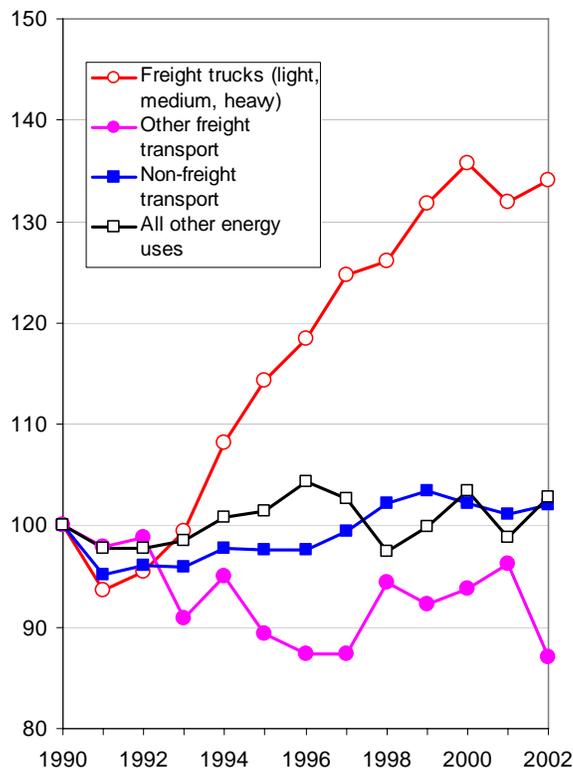
According to an industry representative, if automakers fail to comply, they will face “the sword of Damocles” in the form of legislated requirements to reduce GHG emissions.⁴⁷

2.5. Extraordinary growth in energy use by trucks

In 2002, about 45 per cent of the energy used for transport in Canada was burned in personal vehicles (cars, SUVs, etc.). Another 12 per cent went on other passenger transport including domestic aviation (3 per cent), international aviation (6 per cent), and urban and inter-city surface public transport (3 per cent). The remaining 43 per cent was used for freight and off-road transport, and almost three quarters of this was used in trucks.⁴⁸ As is illustrated in Box 6, the growth in energy use by trucks has been extraordinary, whether in comparison with energy use for other transport or for non-transport activities. Truck energy use increased by 34 per cent *per capita* between 1990 and 2002. Energy use for other freight transport purposes fell, and energy use for other transport purposes, almost entirely the movement of people, grew by two per cent per capita over this period. It was essentially keeping pace with population growth, which was 13 per cent.

The remarkable increase in energy use by trucks on Canadian roads has occurred in spite of reported reductions by about 25 per cent in fuel use per tonne-kilometre of freight car-

Box 6. Changes in energy use per capita for transport modes and for other purposes, 1990-2002 (1990 values = 100)



Source: Natural Resources Canada

ried by medium- and heavy-duty trucks, which perform more than 90 per cent of all tonne-kilometres.⁴⁹ Part of the explanation for this anomaly is that fuel use by these trucks per *vehicle*-kilometre increased by 24 per cent over the period 1990-2002. The improvement in fuel use per tonne-kilometre resulted from 65-per-cent increase in the average load carried by heavy-duty trucks, from 3.0 to 5.0 tonnes.⁵⁰

The 24-per-cent increase in fuel use per vehicle-kilometre occurred in spite of likely reductions in the average unladen weight of trucks on Canadian roads.⁵¹ This probably reflected substantial increases in the power of these trucks, paralleling the above-noted increases in the power of light-duty vehicles. Thus, as for light-duty vehicles, major savings in fuel use could be achieved by reducing truck engine size, adding a few seconds to the time required for acceleration to cruising speeds but achieving major reductions in GHG emissions.

The noted major increase the average load carried by these trucks represents a substantial improvement in fuel efficiency, although the increase should be put in the context of what could be possible. Available data suggest that at least half of the inter-city trucks on the road in Canada are at least half empty, and perhaps a higher share of the trucks moving within urban regions.⁵²

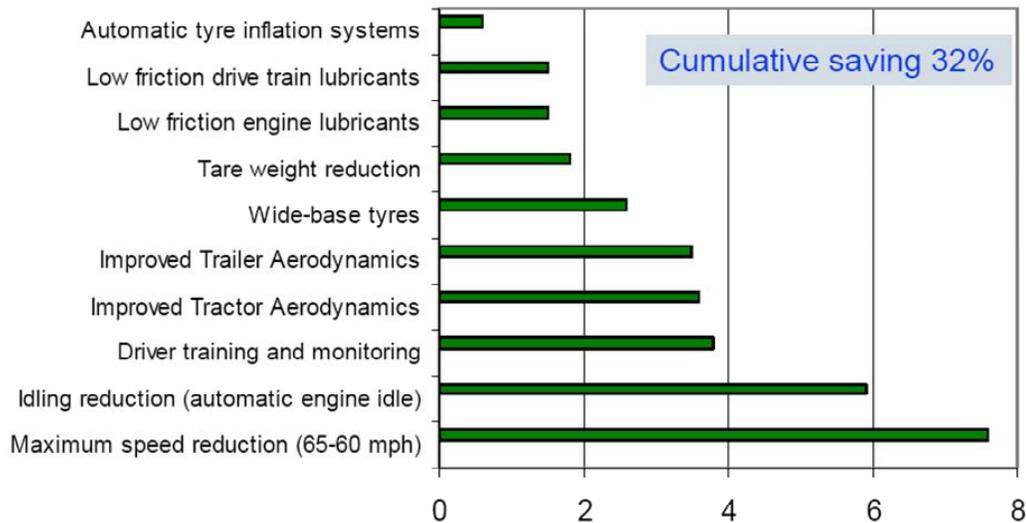
Load factor—i.e., how much of a truck’s maximum carrying capacity is used—is the most important element in the fuel efficiency of road freight transport. Typically, when a truck is one-quarter full it uses *two-and-a-half times* as much fuel per tonne of load as when it is three-quarters full. This surprising conclusion arises because in normal use—except in hilly areas—most fuel is used to move the truck rather than the load.⁵³

Box 7 sets out measures for making better use of trucks’ capacity.⁵⁴ Another kind of measure, difficult to enforce, regulates truck activity according to load factor. For example, in the Swedish city of Gothenburg, trucks that are at least 60-per-cent full, by weight or volume, may use lanes reserved for use by transit vehicles and special loading zones.

Box 7. Measures to improve utilization of vehicle capacity

- Increase backloading/reduce empty running
- Use vehicles with greater carrying capacity
- Greater consolidation of loads – counteract just-in-time pressures
- Use more space-efficient handling equipment
- Rationalize packaging
- Employ computerized vehicle routing and scheduling:
- Employ nominated-day delivery schedules
- Relax monthly order/credit cycle

Source: McKinnon

Box 8. Percent saving in trucks' fuel use from several measures

Source: McKinnon, from Ang-Olson & Schroerer

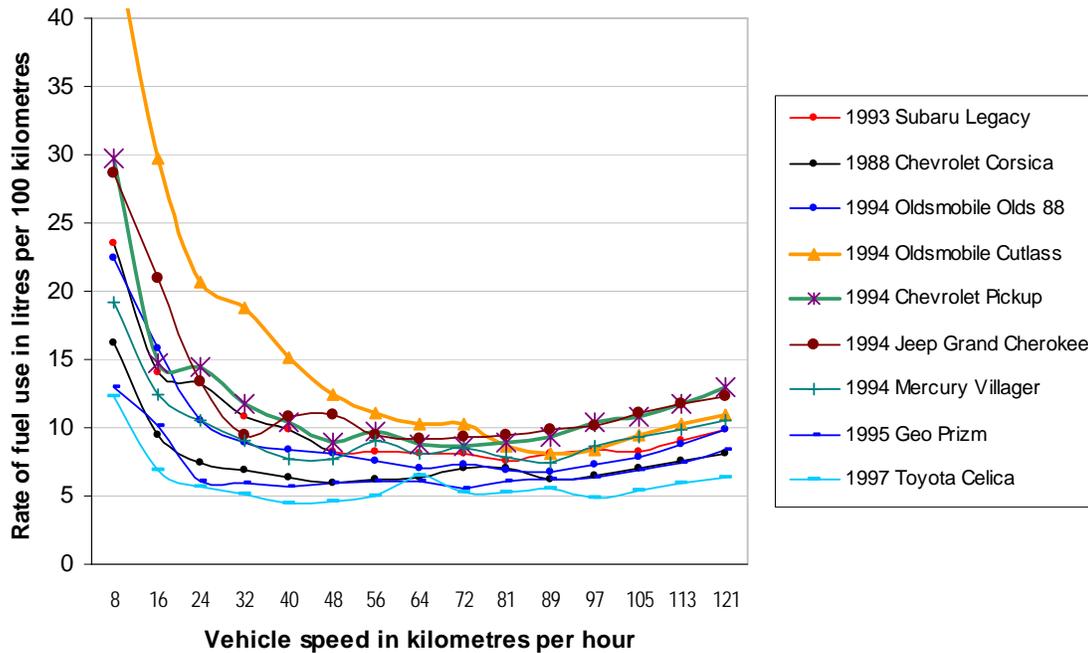
Yet other measures for reducing truck fuel use, and thus GHG emissions, are listed in Box 8, , from a UK presentation based on a U.S. analysis,⁵⁵ together with estimated savings to be gained from the application of each measure. To the measures listed in Box 7 and Box 8 should be added that of reducing the power of trucks on the road, which could be achieved by application of appropriate fiscal or regulatory measures.

Also advantageous, where it can be efficiently achieved, is carriage by rail rather than truck. The simplest comparison between truck and rail fuel use suggests that in 2002 trucks used almost 15 times as much fuel per tonne-kilometre of freight movement as did trains. Partial substitution—engaging in what is known as intermodal transport—has clear advantages.⁵⁶ Even carriage to and between urban locations, for which trucking is believed to be indispensable, could also be susceptible to substitution by rail.⁵⁷ However, not all carriage by truck can be performed by rail, and so the simple comparison of fuel use must be qualified.

2.6. Hybrid ICE-electric vehicles

Hybrid vehicles have their wheels driven by one or more electric motors powered by a battery that is charged by an on-board ICE-generator. In most cases, the ICE can also drive the wheels directly. Overall fuel use can be more than 50 per cent below comparable ICE vehicles, mainly because in hybrid vehicles the battery not the ICE drives the wheels at low vehicle speeds. As shown in Box 9,⁵⁸ the ICE drives in conventional automobiles have high fuel use at operating speeds below 30-40 kilometres per hour. Fuel use at 5-10 km/h is typically about three times that at 40-50 km/h. Electric motors, by contrast, deliver maximum torque per energy unit at low speeds. Indeed, hybrid vehicles, unlike conventional ICE vehicles, can have better fuel economy in urban traffic conditions than on highways, as is evident from the data for the Prius in Box 10.⁵⁹

Box 9. How automobile fuel use changes with vehicle speed



Source: Oak Ridge National Laboratory (U.S.)

Additional fuel economy in hybrid vehicles is achieved through capturing kinetic energy during braking (regenerative braking), by switching off the ICE when decelerating or stationary, and by matching the ICE engine size to the requirements for cruising or modest acceleration, adding battery power when ‘full throttle’ is applied.

Two Japanese manufacturers have some years of experience marketing hybrid vehicles in North America, one a regular passenger sedan and one a compact-size vehicle (see Box 10). North American-owned companies are beginning to market light trucks with what has been described as “mild” hybrid or “mybrid” technology that has no battery-only mode and provides modest reductions in fuel use. Some manufacturers are not pursuing hybrid technology. The car featured in Box 10 that has the lowest fuel use has a regular diesel drive. Its manufacturer had a prototype diesel-powered automobile that uses only one litre per 100 km.⁶⁰

Less progress has been made with respect to the introduction of heavy-duty hybrid vehicles. This technology holds fewer advantages for long-distance vehicles, for which the stop-start cycle is less important, but could be of considerable importance for short-haul trucks⁶¹ and, especially, for urban buses.⁶² Another practical use is for shunting engines in rail yards, for which hybrid electric-ICE locomotives have demonstrated fuel use savings of as much as 60 per cent over convention ICE rail-yard locomotives, with corresponding reductions in CO₂ emissions and larger reductions in emissions of particulates and nitrogen oxides.⁶³

Box 10. Fuel use of efficient and average personal vehicles

	Type	Litres per 100 kilometres			Seats
		City	Highway	Overall	
VW Lupo 3L	Diesel ICE	3.7	2.8	3.1	2 or 4
Honda Insight	Hybrid electric-ICE (gasoline)	3.9	3.3	3.6	2
Toyota Prius		4.0	4.2	4.1	4
Average car	Gasoline ICE	n.a.	n.a.	7.7	4-5
Average other personal vehicle (van, SUV, etc.)		n.a.	n.a.	10.8	3-7

Sources: Natural Resources Canada; manufacturer's information

A version of the hybrid ICE-electric vehicle is the 'plug-in hybrid', which supplements on-board charging with mains-delivered electricity while the vehicle is stationary, thereby further reducing use of fuel for the ICE drive.⁶⁴

The challenge for widespread use of hybrid vehicles is their greater complexity and cost, and perhaps disposal problems with respect to the nickel-based battery systems. Currently marketed hybrids, while expensive, were initially and may still be sold at below production cost.⁶⁵

Hybrid ICE-electric vehicles, as well as providing for reduced oil use, represent a significant bridge to a future in which drive systems for vehicles are based on electric motors rather than ICEs. The vehicle types discussed below—powered by fuel cells or via tethers to rails or wires, and by batteries—are usually thought of as using electric motors only. However, hybrids among them and with ICEs are possible.

2.7. Fuel cell-powered vehicles

Much of the auto industry and many governments appear to believe that hydrogen-fuelled fuel cells will be the main transport technology by 2031.⁶⁶ Fuel cells have the advantage of allowing independently mobile vehicles that use a renewable fuel (e.g., hydrogen produced from wind energy) and produce little pollution from the vehicle.

There are several major technological hurdles that have to be overcome before fuel-cell vehicles become practicable for everyday use.⁶⁷ Fuel-cell-based drive trains are presently too expensive, too unreliable, and provide too little power for the weight of the equipment. A particular challenge is the cost and availability of the platinum catalyst that facilitates the basic reaction of the hydrogen fuel with oxygen in the air. There are challenges

in producing the hydrogen, discussed in Chapter 4, and perhaps even more in storing enough on it on board in a way that meets requirements for reliable everyday use.⁶⁸

According to one industry official, “High-volume production could be 25 years off. I’m less than hopeful about reducing costs sufficiently, and I’m quite pessimistic about solving hydrogen storage issues and packaging these large systems in a marketable vehicle.”⁶⁹

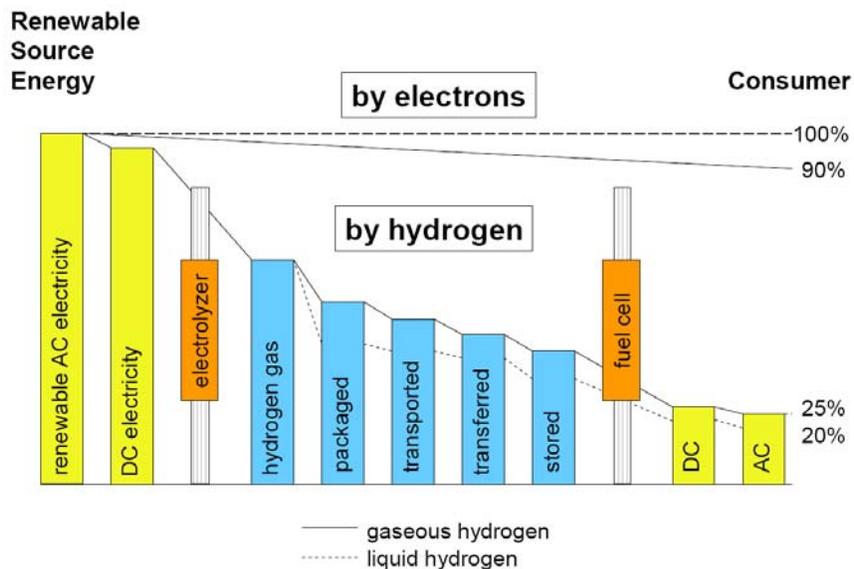
The actual and potential challenges appear large and may be insurmountable in terms of sustaining a transport system that is basically similar to what we have now.

If affordable, reliable fuel cells are developed, if sufficient hydrogen can be produced without climate change impacts, and if distribution and storage challenges can be overcome (see Section 4.1 below), there will be the additional problem of what may be unacceptable energy losses in an energy-constrained world.

How the energy losses arise is illustrated in Box 11,⁷⁰ which shows the losses at the various stages of a system involving generation of electricity from renewable source, use of this electricity to produce hydrogen, distribution and storage of the hydrogen, and use of the hydrogen to generate electricity in a fuel cell. Some 75 or 80 per cent of the energy in the original electricity is lost, according to whether hydrogen is distributed as a compressed gas or a liquid. This loss is compared in Box 11 with the typical loss of 10 per cent when electricity is distributed “be electrons” directly to a motor or other end use.

Where the end use is mobile, electricity transported by electrons can be delivered continuously by a tether, an option elaborated in the next section, or stored on the vehicle in a battery, an option discussed in Section 2.9. From a transport perspective, an on-board hydrogen-fuel cell system is an alternative to the battery for storing electricity on a vehicle.

Box 11. Transport of renewable electricity by hydrogen and by electrons



At the moment, battery systems seem superior in every respect.

2.8. Tethered vehicles

If electrical energy is fed continuously to a moving vehicle via a tether that has contact with a rail or a wire, the advantages of electric vehicles are secured without the range- and weight-related disadvantages of battery-powered vehicles. A further advantage is that there is no energy loss from charging and discharging a battery, which can be in the order of 40 per cent.⁷¹

However, two major disadvantages are introduced: (i) tethered vehicles are confined to routes with appropriate infrastructure (e.g., rails and wires); and (ii) they rely on continuously available, centrally provided power.

The most serious disadvantage of tethered vehicles is their infrastructure requirements. At a minimum, they require wires above existing roads, and the means to power them. According to the type of vehicle, they could also require new rails or other guideways.

A similar infrastructure challenge confronted automobiles 100 years ago. They were mostly confined to summer travel on roads within urban areas. In 1910, the only paved highway in Canada, for example, was a 16-kilometre stretch from Montreal to Sainte-Rose. Present levels of route scope and flexibility took many years to develop. Indeed, an automobile was not driven across Canada until 1946, and the Trans-Canada Highway was not completed until the 1960s.⁷² Today's automobiles and trucks may be even more confined to laid-out roads than those of a century ago, but the road system is extensive, reaching to most parts of southern Canada.

Widespread adoption of tethered vehicles could well involve continued use of the present road system, with the addition of powered overhead wires that can be shared by many. However, vehicles run more efficiently on rails or tracks than on roads, and energy constraints may favour trains and other vehicles confined to special-purpose rights-of-way.

The other disadvantage of tethered vehicles is the need for continuously available, centrally provided power. Toronto's streetcars and subway trains stopped during the major blackout that affected eastern North America on August 14, 2003, but cars and trucks kept on rolling, at least for a time. Then they were stopped in traffic jams caused by non-functioning traffic signals and by line-ups at non-functioning gas stations.

It is nevertheless true that cars and trucks have some additional resilience compared with tethered systems because they carry their own fuel. However, both depend ultimately on heavily centralized systems of energy distribution.

Greater dependence on tethered transport systems would stimulate designs for greater resilience involving more distributed production and greater redundancy. These would in any case be likely features of a more sustainable system of energy supply.

The superior performance of tethered passenger vehicles with respect to energy use is illustrated in Box 12. In each of the three categories of vehicle, tethered vehicles show lower *operational* energy use.

Overall (primary) energy use can be much greater than operational (secondary) energy use, according to how the energy is supplied. For example, electricity produced by a combined-cycle gas turbine generator requires expenditure of about 90 per cent more primary energy in the form of generator fuel as is available in the secondary energy in the electricity.⁷⁹ Similarly, if hydrogen for a fuel cell is produced by electrolysis, the energy content of the electricity used is about 60 per cent higher than the energy content of the hydrogen produced.⁸⁰

Box 12. Energy use in megajoules per passenger-kilometre by various modes.
Tethered modes are shown in colour and italics

Vehicle type	Fuel	Occupancy (pers./veh.)	Energy use (mJ/pkm)
Personal vehicles:			
SUVs, vans, etc. ⁷³	Gasoline	1.70	3.27
Large cars ⁷³	Gasoline	1.65	2.55
Small cars ⁷³	Gasoline	1.65	2.02
Motorcycles ⁷³	Gasoline	1.10	1.46
Fuel-cell car ⁷³	Gasoline	1.65	0.92
Hybrid electric car ⁷⁴	Hydrogen	1.65	0.90
Very small car ⁷⁵	Diesel	1.30	0.89
<i>Personal Rapid Transit⁷⁶</i>	<i>Electricity</i>	<i>1.65</i>	<i>0.49</i>
Public transport between cities:			
Intercity rail (U.S.) ⁷⁷	Diesel		2.20
School bus ⁷³	Diesel	19.5	1.02
Intercity bus ⁷³	Diesel	16.8	0.90
<i>Intercity rail (U.S.)⁷⁷</i>	<i>Electricity</i>		<i>0.64</i>
Public transport within cities:			
Transit bus (U.S.) ⁷⁸	Diesel	9.3	2.73
<i>Trolleybus (U.S.)⁷⁸</i>	<i>Electricity</i>	<i>14.6</i>	<i>0.88</i>
<i>Light rail (streetcar, U.S.)⁷⁸</i>	<i>Electricity</i>	<i>26.5</i>	<i>0.76</i>
<i>Heavy rail (subway, U.S.)⁷⁸</i>	<i>Electricity</i>		<i>0.58</i>

Sources: Various; see notes as referenced by superscript numbers

Box 13. Energy use by freight transport in Finland, in megajoules per tonne-kilometre

Vehicle type	Fuel	Energy use (mJ/tkm)
Truck	Diesel	0.45
Train	Diesel	0.20
<i>Train</i>	<i>Electric</i>	<i>0.06</i>

Source: Andersen et al

With such conversion losses, it is important to consider the primary energy use; this is a better indicator of the energy burden. However, when the secondary energy—which provides the motive power—can be produced with little intermediate conversion, considerations of primary energy use are less important. Examples are gasoline produced from conventional oil and electricity from wind turbines.⁸¹

Tethered vehicles also provide superior performance in freight transport. There are no tethered electric freight trains now operating in North America. The comparison in Box 13 is for Finland.⁸² Not shown are tethered versions of trucks, known as ‘trolley trucks’, which like trolleybuses are powered through an overhead wire. They have been used ex-

Box 14. Trolley truck operating at the Quebec Cartier iron ore mine, Lac Jeannine, 1970s



Source: Hutnyak Consulting

tensively in mining and other off-road operations (see Box 14). Data on the comparative energy use of trolley trucks and regular trucks are not available; the difference between the two is likely comparable to that shown in Box 12 for diesel and electric trains.

The most familiar and frequent use of tethered vehicles in Canada today is for public transit in major urban areas: e.g., trolleybuses and trains in Vancouver, streetcars and trains in Toronto, and trains in Calgary. The last are of particular interest because they are fuelled by renewable wind energy, hence the slogan ‘Ride the Wind’ (Box 15).⁸³

Perhaps the most imaginative and controversial use of tethered vehicles would be for personal rapid transport (PRT), noted in Box 12.⁸⁴ PRT—also known as ‘personal automated transport’—is a generic term for transport systems with the following characteristics:

1. Fully automated vehicles capable of operation without human drivers.
2. Vehicles captive to a reserved guideway.
3. Small vehicles available for exclusive use by an individual or a small group, typically 1-6 passengers, traveling together by choice and available 24 hours a day.
4. Small guideways that can be located above, at or below ground.
5. Vehicles able to use all guideways and stations on a fully coupled PRT network.
6. Direct origin to destination service, without a necessity to transfer or stop at intervening stations.
7. Service available on demand rather than on fixed schedules.

If developed, PRT systems could mostly resolve the challenge of providing electricity efficiently to personal vehicles, albeit vehicles constrained to operation on a guideway.

Box 15. Light-rail train in Calgary



Source: Calgary Transit

Potential developers of PRT systems claim that infrastructure and fuel costs would be low enough to provide widespread penetration, even in quite low-density areas. Some versions would allow for off-guideway, battery-powered operation for the ‘final kilometre’ between guideway and destination. A recent news report indicated interest in PRT development in several U.S. locations and in Dubai, United Arab Emirates.⁸⁵

2.9. Battery-powered vehicles

Battery-powered vehicles have a long history and many advantages, touched on in Section 2.2, but their main drawback, the continuing low power density of batteries, has mostly confined their use to slow-moving vehicles with limited range. Recent attempts to produce and market battery-powered automobiles suitable for everyday use do not appear to have been successful. Electric vehicle enthusiasts claim this reflects lack of industry enthusiasm for the technology. As we write, enthusiasts are mounting a well-publicized campaign to prevent destruction by General Motors of 78 of its remaining EV-1 vehicles.⁸⁶

The enthusiasts note that EV-1s were built in response to California’s ‘zero-emission vehicle’ (ZEV) requirement, which was strongly and successfully opposed by the industry.⁸⁷ Other electric vehicles produced in response to the ZEV requirement are also no longer in production.⁸⁸

If a battery had been developed that had even half of gasoline’s power density—i.e., about that of ethanol—electric personal vehicles might well have prevailed. Then only the recharging rate would have been an issue, and that might have been resolved by ready battery exchange.

Battery-powered vehicles are unlikely to compete with ICE-based vehicles on performance. However, if power and range were to become less important—as might happen, for example, if low speed limits were introduced throughout urban areas—there could be wider interest in battery vehicles. Also, if battery power became the only realistic way of achieving independent mobility, because of high oil prices and lack of other options, then there could be considerable interest.

Battery power will always be suitable for hybrid vehicles, not only the ICE-electric hybrids but also hybrids with fuel cells. For PRT and other tethered vehicles, batteries can provide mobility during power interruptions and off-guideway mobility, including for the first and last few kilometres of a journey where there may be no opportunity to tether to a wire or rail. Battery vehicles could also be useful in less-travelled areas where the cost of tethering infrastructure cannot be justified, and in marine operations, where tethering is difficult and weight is of minimal consequence. In whichever ways transport unfolds, there is likely to be expanded interest in battery operation that will spur further battery development.

2.10. Marine transport

The foregoing sections concerned chiefly road transport, the major user of fossil fuels, and other land-based transport. Marine transport is also a considerable user of fossil fuels, using half as much again as rail within Canada's fresh- and sea-waterways, and a less well specified amount for international shipping.⁸⁹

Most marine applications use diesel ICEs of the kind used in automobiles, trucks and trains (although usually very much larger). Another kind of ICE is also used: gas turbines, better known as the jet engines used in aircraft.⁹⁰ Compared with diesel engines, gas turbines are more expensive and usually use more fuel than ICEs to perform a given amount of work, but are smaller and lighter for a given power output. The diesel engines in large ships burn what is known as bunker fuel, a residual product of refining operations that is heavier and much more sulphur-laden than regular diesel fuel.

Ships perform well over half of the world's freight movement—in tonne-kilometres—and in doing so use about a quarter of the fuel used for freight transport. Overall, per tonne-kilometre they use roughly half the amount of rail, a tenth that of trucks, and one-seventieth that of air freight.⁹¹ Box 16 provides a profile of the world's commercial and military fleets and the estimated share of all ships' energy use by each category.⁹²

In western Europe across the period 1970-2000, short-sea shipping grew threefold, as did road freight, with both performing about the same number of tonne-kilometres. Meanwhile freight movement by rail in Europe, which was at a lower level in 1970 than freight movement by rail or by short-sea shipping, declined further.⁹³ Marine freight activity in Canadian waters has grown more slowly, especially in relation to road freight. In 1990 it

Box 16. World commercial and military fleets, average installed power, and shares of marine energy use

Ship type	Number of vessels	Average installed power (MW)	Share of energy use (%)
General cargo vessels	23,739	3.0	22
Bulk/combined carriers	8,353	6.1	16
Tankers	9,098	5.3	15
Container vessels	2,662	16.4	13
Passenger ships	8,370	2.3	6
Fishing vessels	23,371	0.8	6
Tugboats	9,348	1.7	5
Other registered vessels	3,719	2.0	3
Military vessels	19,646	8.8	14
Total	108,306		100

Source: Corbettl

was responsible for 80 per cent more tonne-kilometres than trucking; but in 2002 was responsible for slightly fewer tonne-kilometres than trucking. Over this period, trucking activity doubled while marine activity grew by less than 10 per cent.⁹⁴

Fuel costs for shipping as a share of all operating costs may be higher than for any other mode.⁹⁵ Moreover, because taxes on fuel are low or non-existent, fuel prices for shipping are exposed to changes in crude oil prices. Nevertheless, fuel use per tonne-kilometre of freight moved seems to have been rising, at least since the mid 1990s.⁹⁶ One reason for the increase could be increasing use of containers,⁹⁷ which make for more efficient handling, particularly intermodal transfer, but can allow less efficient use of a ship's space when containers are not full. Another could be an increase in the speed of shipping.⁹⁸ Even more than for movement through air, the fuel required for movement through water is very much a matter of speed.⁹⁹

Yet another consideration is concern about the high sulphur content of most ships' fuel, and its contribution to local and region pollution. Recent and planned requirements to use cleaner fuels will raise costs substantially.

These considerations have prompted renewed interest in the use of wind to move ships, led by Denmark as an offshoot of its leadership in electricity generation from wind turbines.¹⁰⁰ Two technologies are under exploration. One involves the use of rigid extendable vanes mounted on ship's masts. The other would deploy a large kite (2,000-5,000 square metres) flying at about 500 metres, capable of providing—when the wind is right—propulsive power equal to a large ship's engine.

Other possible replacements for oil as a fuel for large marine vessels are nuclear energy and coal.¹⁰¹

Were aviation to become severely challenged by fuel constraints (see next section), it's possible that intercontinental passenger service by ship could have a revival. The 2004 maiden voyage of the *Queen Mary 2* could be a portent. It is the world's largest passenger ship and the first built specifically for scheduled trans-Atlantic service for 35 years.¹⁰²

2.11. Aviation

Aviation is the mode that is the most challenged by high oil prices because it normally uses the most fuel per passenger-kilometre or tonne-kilometre,¹⁰³ because there do not seem to be ready alternatives to the use of oil products as aviation fuel, and because with low or non-existent taxes it is strongly exposed to rising crude oil prices that are already credited with forcing airlines into bankruptcy. According to one analyst, continuation of jet-fuel costs at current levels will add US\$600 million to U.S. airlines' operating costs for the January-March, 2005 quarter, 11 per cent higher than budgeted. Despite an expected increase in passengers, the industry is set to lose as much as \$2.5 billion this year, driving cumulative losses since 2000 to \$33 billion.¹⁰⁴

There have been substantial improvements in aviation fuel efficiency during the last two decades. For example, fuel use by U.S. domestic and international carriers fell 34 per cent per passenger- or tonne-kilometre since 1986. About half of this improvement was achieved through technical or operating measures and half through better load factors for passengers and freight.¹⁰⁵ The rate of reduction in fuel intensity appears to be declining, and thus perhaps no more than similar improvements can be expected over the next two decades.¹⁰⁶

Moreover, there are particular concerns about aviation's contribution to potential climate change. It contributes in at least three ways. The first is that it burns fossil fuel thereby releasing carbon dioxide. In this, it is no different from almost all other transport, except that the rates of fuel burn per second and per person- or tonne-kilometre are higher than for other modes.

Another way in which aviation contributes to potential climate change is that it results in production of ozone at the boundary of the troposphere and the stratosphere—the tropopause—i.e., at a height of about 10 kilometres, where most long-distance aircraft fly. This happens to be the height at which ozone is the most effective as a greenhouse gas, and where it has a relatively long residence time.¹⁰⁷

A third contribution comes for the formation of contrails when the warm humid aircraft exhaust gases mix with the colder drier ambient air. The water precipitates out on particles in the exhaust plume. Persistent ice is formed that traps heat near the Earth's surface.¹⁰⁸

The result of these and other effects, according to the Intergovernmental Panel on Climate Change (IPCC),¹⁰⁹ is that burning a litre of jet fuel at the height where most commercial aircraft vehicle-kilometres are performed has two to four times the radiative forcing effect of burning a litre of fuel at sea level. Work done since the IPCC report was prepared generally supports this conclusion.¹¹⁰

There appear to be no ready solutions to aviation's strong contribution to climate change beyond attempts to increase the fuel efficiency of aircraft and to reduce the amount of air travel and the amount of movement of freight by air.

The aviation industry nevertheless projects major increases in travel by air worldwide. For example, the Director-General of the International Air Transport Association (IATA), the industry coordinating group, said in January 2005 that *international* air travel had returned to and will stay at its historic annual growth rates of five to six per cent.¹¹¹ Carried forward to 2030, a six-per-cent annual growth rate would represent more than a fourfold increase in air travel over 2005 levels. Even higher rates of growth in travel are anticipated countries undergoing rapid economic growth, e.g., India, where annual increases of 15 per cent or more are anticipated, at least until 2010.¹¹²

For the U.S., the Federal Aviation Administration recently projected for the 2004-2016 period a 44-per-cent increase in enplanements and a 62-per-cent increase in passenger-

kilometres, with larger increases in each case for international than for domestic flights.¹¹³ Projections are not available for Canada, but the Greater Toronto Airports Authority expects that use of Pearson Airport will almost double between 2002 and 2020.¹¹⁴ The total amount of air travel within Canada has hardly changed during the last two decades; travel to the U.S. has doubled, and other international travel has tripled.¹¹⁵

Air freight, much of which occurs in passenger aircraft, has been increasing at a higher rate than passenger travel, and is expected to continue to do so. One major aircraft manufacturer expects that air freight activity will increase by an annual average of 6.2 per cent over the period until 2024, compared with 5.2 per cent for passenger activity.¹¹⁶

There is a major disconnect between aviation's fuel-price predicament and the climate change concerns, on the one hand, and the apparent optimism the aviation industry, on the other hand. The continuing apparent success of some low-cost carriers has spurred part of the optimism. According to one analysis, 60 or more new airlines have begun business since September 2001. Most have been low-cost carriers, aided, according to one source, by some or all of the following factors:¹¹⁷

- the adverse impacts of disease, terrorism, and business conditions that caused traditional carriers—also called 'legacy' carriers—to contract, leaving room for low-cost carriers to expand;
- resulting over-supply of aircraft, pilots, and other personnel at bargain prices;
- availability of off-the-shelf software to run low-cost internet booking systems, including automatic fare escalators as a plane fills up;
- availability of a proven business model, developed first in the U.S. (Southwest Airlines), and copied elsewhere, beginning in Europe (e.g., Ryanair), continuing in Canada with WestJet, and most recently extending to Asia.

The low-cost carriers have flourished by taking advantage of lower labour and other costs compared with established carriers, but with the result that the fuel costs' share of operating costs is higher. Thus, as fuel costs rise, low-cost carriers are more exposed to the increases. The collapse in 2005 of Canada's Jetsgo is a case in point.¹¹⁸ A recent analysis of the activities of low-cost carriers in Europe pointed to "a wide range of threats" to the business model they employ.¹¹⁹ These include "sustainability threats, such as the introduction of an environmental economic instrument". Other identified threats include market saturation, the viability of the business model's dynamic pricing structure, safety concerns, competition from established carriers and charter airlines, competition from within the low-cost carrier sector, and modal substitution (chiefly high-speed rail in Europe and Japan, and other places outside North America). The analysis also pointed to a lack of strategic management in this sector, which was found to be a characteristic of the airline industry as a whole.

In the meantime, cheap flights are said to be doing more to integrate Europe than "any numbers of diplomats and ministers".¹²⁰ Low-cost airlines carried 80 million passengers in Europe in 2004, up from 47 million in 2003, including, for example, numerous UK purchasers of weekend homes in France. Some prices are so low there is speculation

about more profitable sidelines including smuggling and piracy. One of the present authors flew the 914 kilometres from London to Berlin in November 2004 on an air ticket that cost Can\$2.30 (plus taxes etc.), a slightly higher per-kilometre fare than the Can\$1.00 (plus taxes, etc.) he paid earlier in the year to fly the 400 kilometres from Toronto to Ottawa with what was then the low-cost arm of Canada's major airline. The likely per-passenger fuel cost in mid-2004 for a 400-kilometre flight was in the order of Can\$10-15, and perhaps Can\$20-25 for a 900-kilometre flight.¹²¹

An alternative view of the low-cost carrier phenomenon is that it is a symptom of the fuel and other pressures faced by the industry. These carriers offer less for less and thereby help stave off the impact of rising costs on the whole industry. A major part of their cost advantage over legacy carriers would appear to be their freedom from making pension contributions.¹²²

A reasonable prognosis for air travel may not be that of the aviation industry but rather one rooted in the realities of oil availability, discussed below in Chapter 3. As oil prices rise, perhaps steeply, fares will rise and fewer rather than more trips will be made. In such a perspective, aviation's environmental impacts could be closer to self-correction through fuel price increases than those of other transport modes.¹²³

Already some far-thinking members of the travel industry are thinking beyond aviation as we know it. For example, the German company TUI AG, which styles itself as "Europe's leading travel group" says it is working on a scenario whereby long-haul travellers would be transported by airships in 2020.¹²⁴ Airships travel considerably more slowly than jet aircraft, require less infrastructure, and may be more fuel efficient.¹²⁵ Their main advantage could be the ability to use a wider variety of fuels than regular aircraft, including electricity from photovoltaic cells on the airship's surface.

Aviation as we know it could continue by being given priority in the availability of fossil fuels, or through use of biofuels¹²⁶ or the products of coal liquefaction, albeit at a high price. Few people would fly, especially for leisure purposes, reflecting findings that the price elasticity of such travel is high. A recent meta-analysis found that the median of 55 estimates of the price elasticity of international long-haul tourism travel by air was -0.99, the median of 16 estimates of such travel for business purposes was -0.27.¹²⁷

Instead, there could be more travel by train within continents,¹²⁸ and more travel by ship between continents.¹²⁹

2.12. Information technology

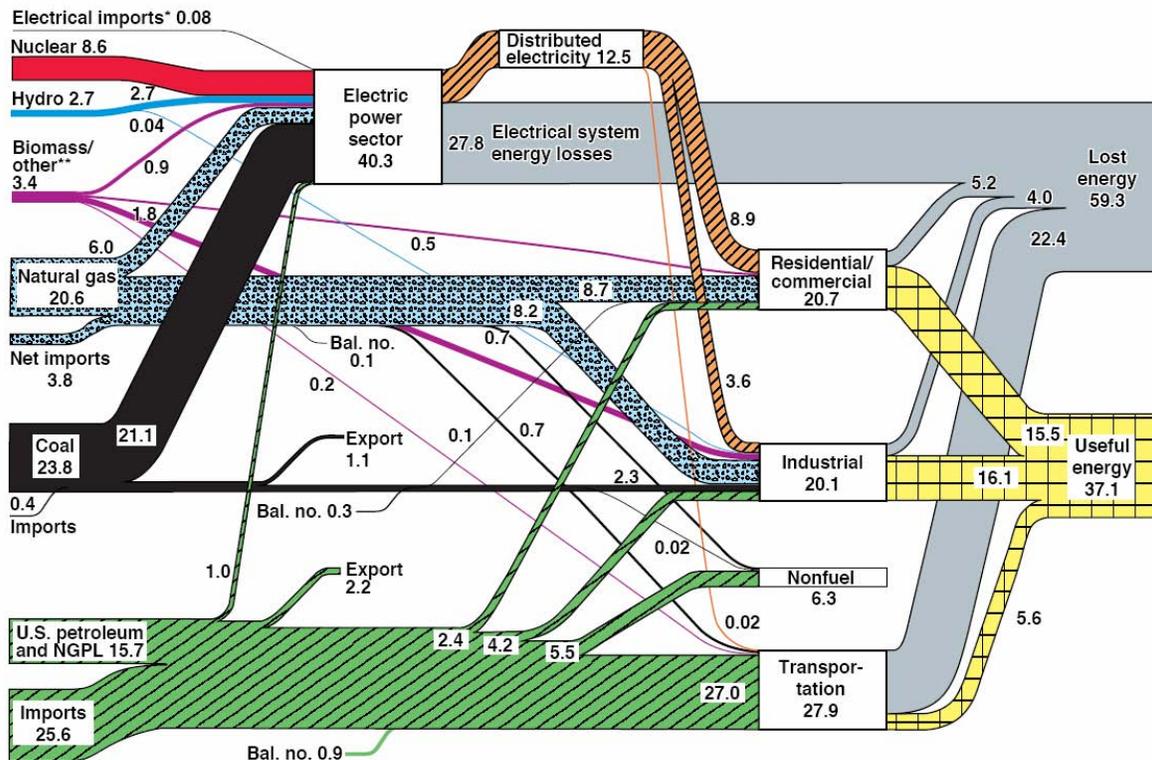
Information technology (IT) is an important topic for the future of transport. For the movement of both people and freight, IT can both substitute for transport activity and facilitate it. Examples of substitution are meeting by videoconference rather than in person, and sending an electronic file rather than the document itself. Facilitation is more complex. IT can reduce transaction costs and thus overall costs. Facilitation can also occur when people correspond by e-mail easily at a distance, and then want to meet, and when

it is more convenient and less costly to order an item on the Web from a distant supplier than from a nearby store.

Perhaps the main effects of IT on transport are on the freight side. IT has played a considerable role in securing the revolution in supply chain management that appears to have caused the ongoing increases in freight transport activity, but it also has much potential to help with offsetting these increases.¹³⁰

As with many of the topics touched on in this report, the roles of IT in transport and energy issues warrant much longer treatment than is provided here.

Box 17. U.S. primary and end-use energy consumption, 2002



Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2002*.
 *Net fossil-fuel electrical imports.
 **Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.

June 2004
 Lawrence Livermore
 National Laboratory
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Chapter 3. Fuels for internal combustion engines

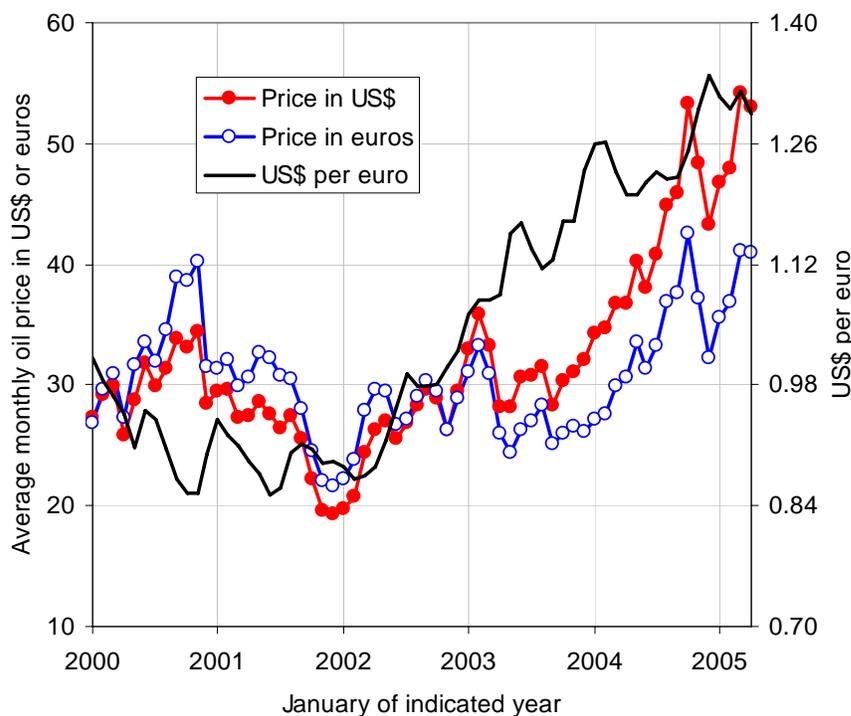
By way of introduction to Chapter 3 and Chapter 4, the diagram in Box 17 on the previous page shows the energy context for the use of oil and other energy sources in the United States.¹³¹ The right-hand side of such a diagram for Canada would be quite similar, but the left side would be rather different. For example, as is noted below, about 70 per cent of Canada's electricity is produced from hydroelectric power. Also, more than 70 per cent of Canada's oil production is exported, and almost 60 per cent of oil consumption is imported.

3.1. Oil and other petroleum liquids

In early April 2005, crude oil prices reached their all-time high of about US\$58 in current dollars,¹³² although by early June they were about \$5 lower.¹³³ There has been considerable speculation as to why the price rose so high, and why it stays at a much higher than expected.¹³⁴ Part of the reason is a decline in the value of the U.S. dollar, particularly vis-à-vis the euro, and compensatory action by oil traders.¹³⁵ This is illustrated in Box 18,¹³⁶ where it can be seen that the price in euros has been relatively constant. However, it has risen in the last year even in euro terms.

Explanations of the unusually high oil prices are essentially of two kinds.¹³⁷ Both point to unexpectedly high levels of demand for oil, particularly by China, and to supply chal-

Box 18. Oil prices in U.S. dollars and euros (left-hand scale), and exchange rate (right-hand scale)



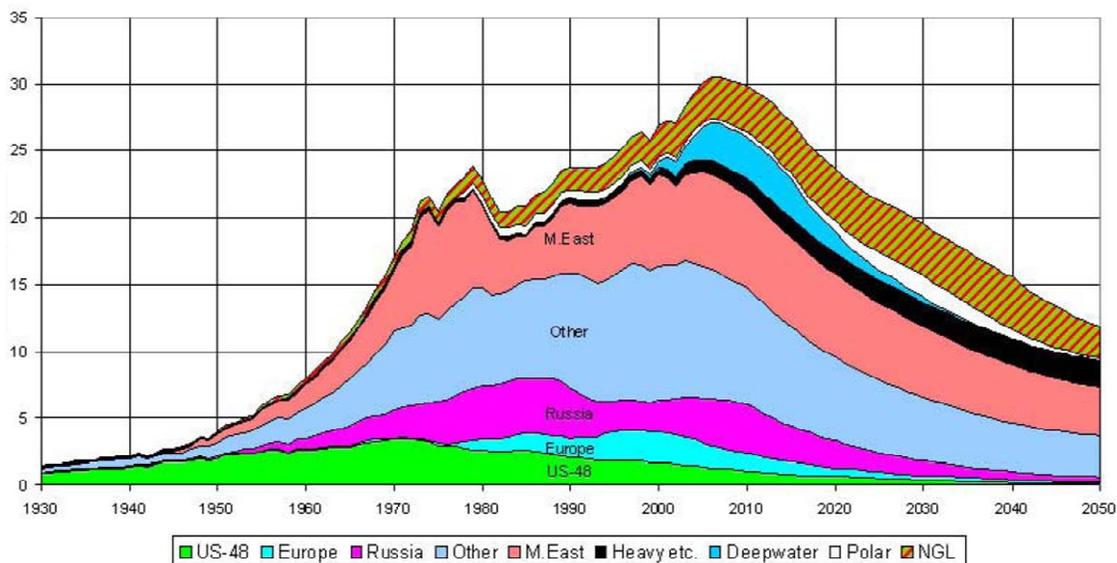
lenges. One says the supply challenges are temporary, the result of instability in the Middle East, Nigeria or Venezuela, or improvidence on the part of oil companies, or unreasonable restrictions on drilling, or some combination of these factors. The other kind of explanation involves the proposition that an inevitable peak in world oil production has been or is being reached, and that the supply of oil cannot thus keep up with demand.

The first kind of explanation tends to be advanced by analysts who are inclined to believe that oil supply is mostly a matter of price.¹³⁸ At a given price there is only so much oil that can be economically extracted. Exhaustion of this oil creates an imbalance of supply and demand that raises prices and enables production of harder-to-extract oil. This process can continue more or less indefinitely, facilitated by technological advances that lower the cost of difficult extraction. The process may be eventually restrained by unwillingness to pay high prices, and consequent development and use of alternative, possibly better fuels. For example, one Canadian researcher has argued that hydrocarbon resources are not inherently fixed or limited, that resource limits do not for practical purposes exist. He argued that the only realistic limitation to gasoline production is price.¹³⁹

The second kind of explanation tends to be advanced by analysts who disagree with the above formulation in one important respect. It is whether production of oil could continue to grow more or less indefinitely, even with sufficient investment and adequate technology. These analysts argue that the nature of oil wells is such that the first half of what is recoverable can be easily and cheaply extracted, but extraction of the second half becomes progressively difficult and costly. Integration of this pattern across a large number of wells produces a curve with peak production at or near the point at which half of what is recoverable has been extracted.¹⁴⁰

Application of the latter kind of analysis led to an accurate prediction of a U.S. produc-

Box 19. World production of conventional oil (by region), unconventional oil, and natural gas liquids. actual and estimated. 1930-2050 (billions of barrels per year)



Source: Uppsala Hydrocarbon Depletion Group

tion peak in 1970.¹⁴¹ Since then, a production peak has been encountered in several other major oil-producing countries, notably Argentina, Indonesia, Norway, and the United Kingdom.¹⁴² A peak in *world* production is expected during the next decade, as is illustrated in Box 19, which portrays what may be the most authoritative analysis of this kind.¹⁴³

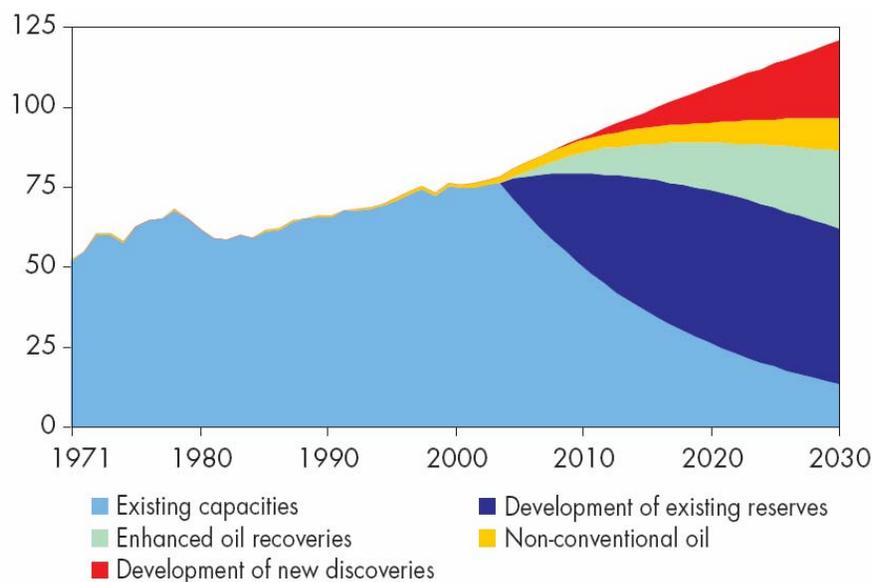
The first kind of explanation holds that more investment would increase the rate of discovery and the ability to extract oil from mature wells. The second kind of explanation notes that the world is more or less mapped, and there is little more oil to be found, and that the ability to enhance recovery from mature wells is marginal at best.

Those who espouse the second perspective also note that recent high prices mean that the oil industry is awash with money, and yet the pace of investment has not increased, suggesting that low returns would be expected.¹⁴⁴ Others respond that the industry has been preoccupied with mergers and with demanding shareholders who want early returns.

Government energy agencies have so far embraced the first perspective. The most prestigious, the Paris-based International Energy Agency (IEA), concluded in its *World Energy Outlook 2004* that “global production of conventional oil will not peak before 2030 [the end of IEA’s outlook period] if the necessary investments are made”.¹⁴⁵ However, with a nod to the other perspective, the *Outlook* acknowledged that production could peak around 2015 if less oil is found than IEA expects.¹⁴⁶

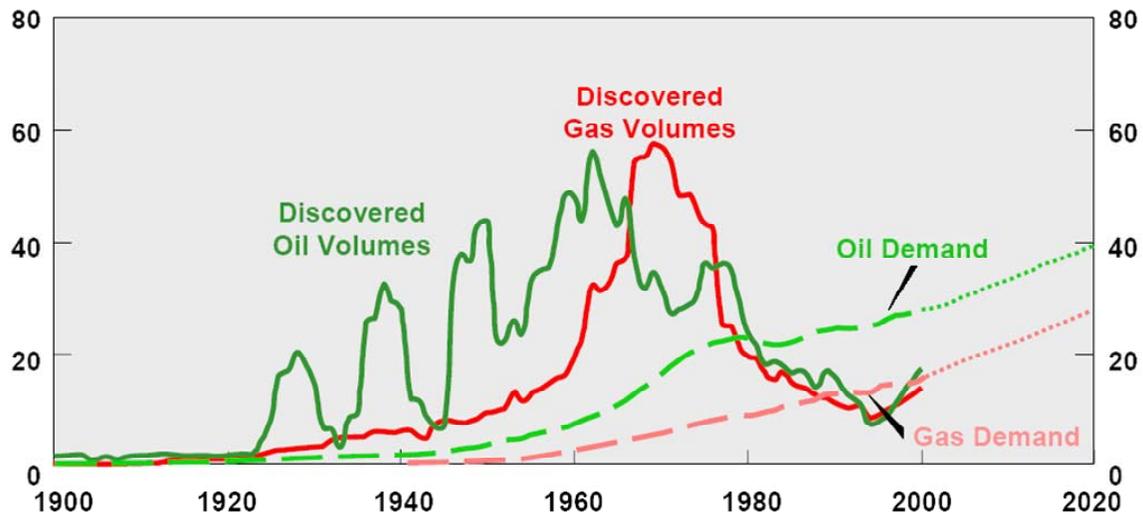
Details of the IEA’s base projection are in Box 20.¹⁴⁷ Every feature of the projection is disputed,¹⁴⁸ except the imminent decline in production from currently producing wells—“existing capacities” in the chart—and the production of non-conventional oil, e.g., oil

Box 20. World oil production by source, 1971-2030 (in millions of barrels per day)



Source: International Energy Agency

Box 21. World discoveries and production of crude oil and natural gas, actual and estimated, 1900-2020 (in billions of oil-equivalent-barrels per year)



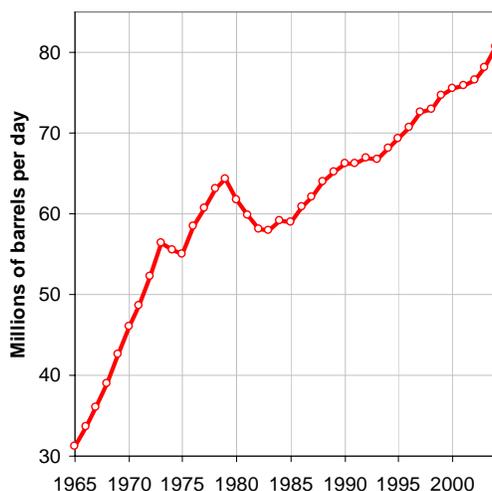
Source: ExxonMobil

from Alberta's oil sands. For example, the yield from "development of new discoveries" is posited in the face of evident dramatic decline in such discoveries. The decline is noted in IEA's *Outlook* report,¹⁴⁹ but is illustrated more clearly in Box 21, an industry source.¹⁵⁰ With such a progressive decline in oil discoveries since the early 1960s, it's difficult to believe there will be a turnaround sufficient to support the projection in Box 20. Similar arguments based on recent performance can be made in respect of the "development of existing reserves" and "enhanced oil recoveries" elements of IEA's projection, both of which appear to be unduly optimistic.

Major oil companies appear to be behaving at odds with IEA's projections, channelling their recent profits into shareholder payouts, higher wages, and merger and acquisition activity designed to consolidate control of existing reserves. Few of the major integrated oil companies have increased their exploration and development budgets for new reserves in proportion to their growth in profit from existing reserves, suggesting that a supply-side constraint is operative.¹⁵¹ Moreover, even where stated reserves are rising, production may be falling more quickly than is offset by the new discoveries.¹⁵²

Demand (i.e., actual consumption) shown in Box 22 is the other side of the equation.¹⁵³ With some interruptions there has been continuous growth since the 1960s, at an average annual rate of 5.3 per cent from 1965-1979 and of 1.6 per cent from 1983-2003. What may be a particularly steep increase between 2003 and 2004 (3.4 per cent, compared with the annual average of 1.6 per cent during the previous decade, although data are preliminary) likely reflected extraordinary growth in China's consumption, which grew by 15.6 per cent over 2003, compared with an annual average of 7.5 per cent during the previous decade. Even more important for the world oil market was the growth in China's imports during 2004, by 43 per cent over 2003. This remarkable rise in imports may have occurred because China had reached its peak in indigenous production of oil in 2003; pro-

Box 22. World consumption of crude oil, 1965-2004 (in millions of barrels per day)



Source: BP Statistical Review of World Energy

duction fell by 1.1 per cent in 2004. To accommodate the large growth in use, imports—now accounting for almost half of China’s consumption—had to rise even more. In 2002, China had passed Japan to become the second largest consumer of oil (although in 2003 using only 31 per cent of U.S. consumption).¹⁵⁴

In recognition that we might be at an extraordinary juncture in the matter of oil availability, the International Energy Agency held a high-level workshop in March 2005 entitled ‘Managing oil demand in transport’.¹⁵⁵ A key purpose of the workshop was review of a draft report on IEA’s ‘Saving oil in a hurry’ study, now published in book form.¹⁵⁶ It argues that government should be prepared to act to reduce demand in the event of a sharp rise in the price of oil. The most effective measures in reducing oil consumption for transport are considered to be behavioural restrictions such as limits on driving, incentives for carpooling, and speed restrictions.

The position proposed here is that such measures be introduced *in anticipation of* a sharp rise in the price of oil, rather than when it has happened.

Perhaps the significant feature of IEA’s proposals is that they might not have been made at all a year ago. The context of discourse about oil has changed. Indeed, part of the challenge in preparing the present document has been the rapid validation of the notion of peak oil as part of ongoing discussion and analysis. When we began work on this paper in December 2004, discussions of production peaks had something of a fringe nature, the fancy of geologists with little grasp of economic principles or of conspiracy theorists who frame all questions about oil in geopolitical terms.

Now, recognition that we may be at or approaching a peak in world oil production is commonplace, finding a place on the front page of business sections of Canadian newspapers,¹⁵⁷ and in the advice provided by Canadian investment analysts.¹⁵⁸

Box 23. Proposed Oil Depletion Protocol

WHEREAS the passage of history has recorded an increasing pace of change, such that the demand for energy has grown rapidly in parallel with the world population over the past two hundred years since the Industrial Revolution;

WHEREAS the energy supply required by the population has come mainly from coal and petroleum, having been formed but rarely in the geological past, such resources being inevitably subject to depletion;

WHEREAS oil provides ninety percent of transport fuel, essential to trade, and plays a critical role in agriculture, needed to feed the expanding population;

WHEREAS oil is unevenly distributed on the Planet for well-understood geological reasons, with much being concentrated in five countries, bordering the Persian Gulf;

WHEREAS all the major productive provinces of the World have been identified with the help of advanced technology and growing geological knowledge, it being now evident that discovery reached a peak in the 1960s, despite technological progress, and a diligent search;

WHEREAS the past peak of discovery inevitably leads to a corresponding peak in production during the first decade of the 21st Century, assuming no radical decline in demand;

WHEREAS the onset of the decline of this critical resource affects all aspects of modern life, such having grave political and geopolitical implications;

WHEREAS it is expedient to plan an orderly transition to the new World environment of reduced energy supply, making early provisions to avoid the waste of energy, stimulate the entry of substitute energies, and extend the life of the remaining oil;

WHEREAS it is desirable to meet the challenges so arising in a co-operative and equitable manner, such to address related climate change concerns, economic and financial stability and the threats of conflicts for access to critical resources.

NOW IT IS PROPOSED THAT:

1. A convention of nations shall be called to consider the issue with a view to agreeing an Accord with the following objectives:
 - a. to avoid profiteering from shortage, such that oil prices may remain in reasonable relationship with production cost;
 - b. to allow poor countries to afford their imports;
 - c. to avoid destabilizing financial flows arising from excessive oil prices;
 - d. to encourage consumers to avoid waste;
 - e. to stimulate the development of alternative energies.
2. Such an Accord shall have the following outline provisions:
 - a. No country shall produce oil at above its current Depletion Rate, such being defined as annual production as a percentage of the estimated amount left to produce;
 - b. Each importing country shall reduce its imports to match the current World Depletion Rate, deducting any indigenous production.
3. Detailed provisions shall cover the definition of the several categories of oil, exemptions and qualifications, and the scientific procedures for the estimation of Depletion Rate.
4. The signatory countries shall cooperate in providing information on their reserves, allowing full technical audit, such that the Depletion Rate may be accurately determined.
5. The signatory countries shall have the right to appeal their assessed Depletion Rate in the event of changed circumstances.

Source: Oil Depletion Analysis Centre (UK)

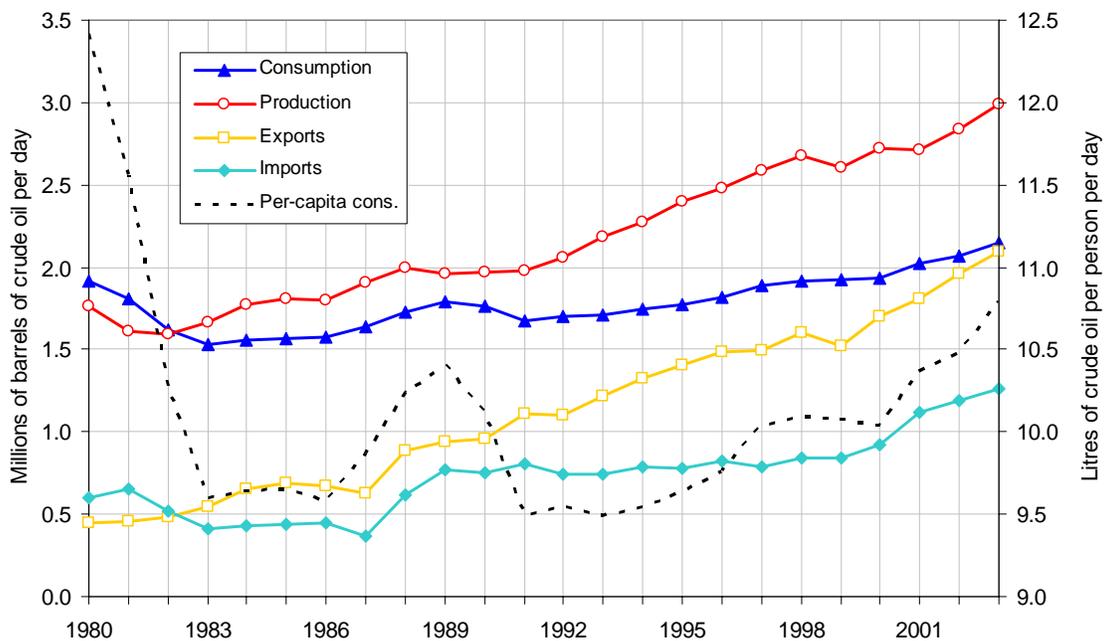
Action on the matter is coalescing around an Oil Depletion Protocol first presented at a workshop in Lisbon, Portugal,¹⁵⁹ in May 2005 and given front-page treatment by the *Financial Post*.¹⁶⁰ The proposed Protocol is set out in Box 23.¹⁶¹ The present authors believe that widespread implementation of a protocol of this type may be more urgent than implementation of the Kyoto Protocol. Both should be done, but with priority given to addressing the challenges posed by reduced availability of low-cost oil.

3.2. Canadian oil production and consumption

Canada, according to some estimates, has the second largest petroleum reserves in the world,¹⁶² and thus might be considered immune to supply constraints. Canada's production, consumption, imports, and exports of oil are shown in Box 24 against the left-hand scale.¹⁶³ In 2003, Canada exported just over 70 per cent of its oil production (to the U.S.) and imported almost 60 per cent of its consumption (with almost half of this coming from Europe, mostly in the form of refined oil products). Canada supplied 17 per cent of U.S. imports of oil and oil products in 2003 (10 per cent of U.S. consumption), more than any other country and almost as much as the whole of the Middle East, which supplied 20 per cent of U.S. imports.

The data in the previous paragraph illustrate the extent to which Canada is embedded in world oil trading arrangements. There are not presently the means to provide a ready supply of Alberta oil to eastern Canada, which remains heavily dependent on imports.

Box 24. Canadian production, consumption, exports, and imports of oil (left scale) and per-capita consumption (right scale), all for 1980-2003



Source: BP

Moreover, the North American Free Trade Agreement could impede development of such means. It contains an energy-specific clause that applies only to Canada and the U.S., and in effect only to Canada. It is that Canada may not act in such a way as to reduce the share of an energy resource exported to the U.S. below the average for the most recent three-year period.¹⁶⁴ Thus, as the share of Canada's oil production exported to the U.S. rises, from 53 per cent when NAFTA was signed in 1992 to above 70 per cent in 2003, Canada incurs a growing obligation to supply energy to the U.S. and a growing inability to make Canadian energy production available to Canadians. The only remedy available within NAFTA may be withdrawal from NAFTA, which would require no more than the filing of six months notice.¹⁶⁵ But such action could have a major adverse effect on the Canadian economy, about 30 per cent of which is linked to trade with the U.S.¹⁶⁶ This perhaps accounts for the greater popularity of NAFTA in Canada.¹⁶⁷

Box 24 shows that Canadian oil consumption has been relatively constant, although increasingly provided from imports, whose share of consumption rose from 44 per cent in 1992 to 59 per cent in 2003. The dashed line in Box 24, read against the right-hand scale, shows that Canada's per-capita consumption is considerably below what it was in the early 1980s, but has been rising steadily since 2000.¹⁶⁸

An additional factor is the recent disposition of China to purchase Canadian fossil fuel resources, presumably for export to China.¹⁶⁹ Exports of oil from Canada to China could mean that more would have to be imported for Canadian use.

Increasingly, Canada's oil production is from oil sands. Synthetic crude oil production—i.e., from oil sands—accounted for 21 per cent of total production in 1993 and 35 per cent in 2003.¹⁷⁰ Production of synthetic crude oil rose by 130 per cent. This production is relatively intensive in its generation of GHGs, resulting in about 80 per cent more emissions per barrel produced than from production of conventional oil.¹⁷¹ Thus, as transport and other activities become increasingly fuelled by oil from oil sands, they make in effect a greater contribution to potential climate change. Production of synthetic crude oil also involves heavy use of natural gas, discussed in Section 3.4 below, and water, availability of which could limit the amounts produced.¹⁷² Recently, the estimated cost of production of oil from oil sands has risen substantially.¹⁷³

**Box 25. Estimates of crude oil prices and gasoline prices
in the event of shortfalls in crude oil production**

	Shortfall in crude oil supply			
	0%	5%	10%	15%
Resulting increase in crude oil price	0%	30%	200%	550%
Crude oil price per barrel (US\$)	\$50	\$65	\$150	\$320
Resulting gasoline pump price (Can\$/litre)	\$0.85	\$1.00	\$1.50	\$2.50

Source: Brookings Institution

3.3. How high could oil prices rise?

The aims of the foregoing analysis were to indicate that a peak in world oil production may be happening or be imminent, that it could cause oil prices to rise steeply, and that Canada is not immune, even though it is a net exporter of oil. How much could prices rise? One U.S. analyst's suggestions are set out in Box 25, translated into Canadian terms and conditions.¹⁷⁴ As prices rise, consumption of oil products will fall, which will reduce pressure on supply and thus moderate or even check the price increase. Some of such an effect has been taken into account in the estimates in Box 25, but it may be too little, or too much. Moreover, governments may choose to regulate prices or consumption, or both, which could dramatically change responses to production shortfalls.

A recent analysis by CIBC World Markets began, "Over the next five years, crude prices will almost double, averaging close to \$77/bbl and reaching as much as \$100/bbl by 2010".¹⁷⁵ The CIBC analysis is roughly consistent with the Brookings Institution analysis set out in Box 25. It points to supply falling short of demand by about nine per cent. According to the Brookings Institution, this would result in a crude oil price of about \$130 rather than \$100 per barrel. One of the papers presented at the 'Managing oil demand in transport' workshop described on Page 36 noted that a nine-per-cent shortfall would raise the price from \$50 to \$100 if the price elasticity of demand were about -0.14 and to about \$130 if the elasticity were slightly lower, i.e., about -0.12.¹⁷⁶ One analysis, for 23 countries, produced a median value for the short-run price elasticity of demand for crude oil of -0.055 and a median value for the long-run elasticity of -0.182.¹⁷⁷

The territory of shortfalls in oil supply is mostly unknown, and needs to be better understood as Canada and the rest of the world face this possibility during the next decade.¹⁷⁸ But, rather than spend much time on such exploration, it may be more productive to figure out how to avoid such shortfalls by reducing dependence on oil. This could be particularly for transport, which—as noted in Section 2.3—accounts for 71 per cent of end-use consumption of oil in Canada and the U.S., with the remainder shared roughly equally between industry, including use as a chemical feedstock, and electricity generation.)

More space is given in this chapter to oil than to other fuels because of the importance of oil for transport. In Canada and the U.S., more than 97 per cent of motorized transport is fuelled by oil products,¹⁷⁹ and thus details about the availability of oil are of paramount importance.

3.4. Natural gas

Natural gas is significant for a discussion of transport fuels in several ways:

- As compressed natural gas (CNG) it can be used a fuel for ICEs with very little adaptation. Liquefied natural gas (LNG) can also serve as a transport fuel.¹⁸⁰ Natural gas can also serve as the fuel for some fuel cells.¹⁸¹
- Liquid by-products of natural gas production—natural gas liquids, or NGLs—are a significant source of liquid fossil fuel (see Box 19). Propane is the best known NGL

and is used directly as a transport fuel (e.g., for cabs in Hong Kong).¹⁸² Butane is also well known, as a lighter fuel. NGLs can be readily blended with and substituted for other liquid oil products.

- Using the Fischer-Tropsch process, natural gas can be converted into a gasoline or diesel fuel substitute.¹⁸³
- Natural gas is the feedstock for about 95 per cent of U.S. production of hydrogen,¹⁸⁴ discussed below as a potential transport fuel.
- Natural gas is a major source of heat energy for extracting bitumen from oil sands and for ‘hydrogenating’ the bitumen so that it becomes less of a carbon-rich tarry substance and more of a liquid fuel with the consistency and volatility of gasoline.

Natural gas may also be significant as a model of how fossil fuel production reaches a peak and what happens subsequently, as will be discussed below.

For the most part, natural gas burns more cleanly than gasoline and diesel fuel, but “although CNG provides clear reductions in NO_x and PM compared with regular diesel buses, this advantage may disappear when compared with ‘clean-diesel’ buses operating on ULSD [ultra-low sulphur diesel] with catalytic particulate filters.”¹⁸⁵

Supplies of natural gas are already constrained in North America, where peak production likely occurred in 2002.¹⁸⁶ This is the year when Canadian production peaked. U.S. production peaked many years earlier, with supplies to U.S. users being maintained chiefly through imports from Canada. According to one observer, “A decade ago, Alberta’s gas industry easily met its share of North American demand by drilling 4,000 new wells a year; today it can barely keep production flat with 15,000 new wells a year”.¹⁸⁷ The “supply deficit” in natural gas has been described by one informed commentator as “the most serious problem facing the U.S. economy during the remainder of this decade”.¹⁸⁸

Three sources of new or additional supply are expected to provide some relief. One involves the construction of one or more pipelines from Canadian and U.S. Arctic sources.¹⁸⁹ Another would involve much expanded imports from elsewhere in the form of LNG.¹⁹⁰ The third involves extraction of methane from coal beds, already a source of almost ten per cent of U.S. production, but providing much greater challenges in Canada.¹⁹¹ However, even optimistic projections of supply from these sources do not suggest that they could offset the decline in production from conventional wells in Canada and the lower 48 states.

A fourth source, presently speculative, has the potential to provide sufficient relief. It is deepwater methane hydrates, described by the U.S. Geological Survey as “gas molecules, usually methane, each surrounded by a cage of water molecules”. They are said to contain twice as much fossil fuel energy as all other worldwide sources combined. The immense amounts of them and the richness of their deposits “may make methane hydrates a strong candidate for development as an energy resource”.¹⁹²

In 2003, the U.S. Department of Energy began systematic exploratory drilling for methane hydrates began at Alaska's North Slope.¹⁹³ In April 2005, it sent a drilling vessel to explore whether usable methane, i.e., natural gas, can be extracted from hydrate deposits in the Gulf of Mexico.¹⁹⁴ A fear about increased use of natural gas is release of methane into the atmosphere, particularly from what may be uncontrollable methane hydrates. Methane has at least 21 times the global warming potential per molecule as carbon dioxide.

Supplies of conventional natural gas are relatively plentiful in other parts of the world. However, discoveries worldwide peaked a decade or so after discoveries of oil peaked (see Box 21). Thus, as world production of oil is expected to peak during the next decade or two, so might natural gas production peak within two or three decades. The peak in North American production has already resulted in large increases in wholesale and retail prices.¹⁹⁵ As world production of natural gas reaches a peak, prices elsewhere will rise, thus reducing the attractiveness of both LNG imports and outsourcing of manufacturing from North America to avoid high prices of natural gas as a fuel and a feedstock.

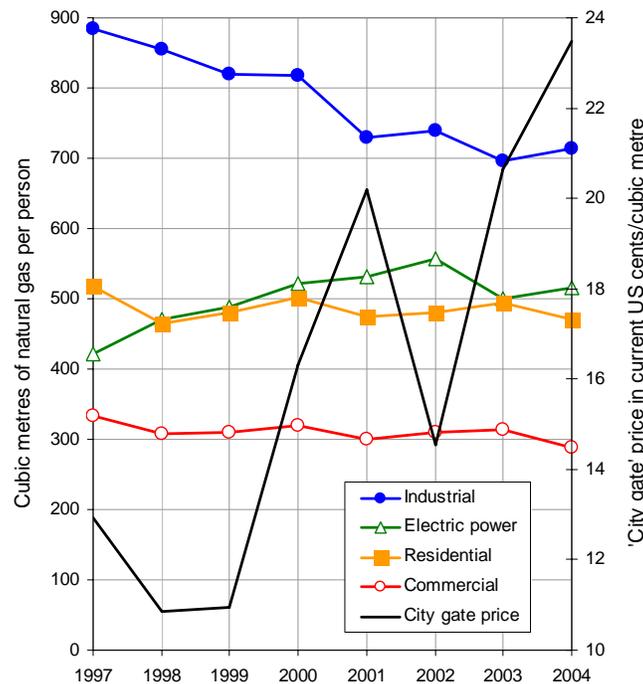
Reducing natural gas use as fuel or feedstock below projected levels in order to avoid high prices has been referred to by economists as 'demand destruction'.¹⁹⁶ According to one observer, writing about the U.S. in 2003, when high natural gas prices were taking hold, "At least a dozen fertilizer plants have declared bankruptcy. Ethylene production has been cut back significantly. Some other chemical operations have been shifted overseas. Energy efficiency measures have been instituted at many facilities. And virtually every industrial boiler that is capable of burning residual fuel appears to have switched to fuel oil many months ago and has not switched back to natural gas."¹⁹⁷

Notwithstanding these dramatic observations, the actual impact of the recent extraordinary increases in natural gas prices seems modest. Data for the U.S. across the period 1997-2004 are presented in Box 26.¹⁹⁸ Consumption for industrial purposes, including as fuel and feedstock, fell per-capita during the period 1997-2004, suggesting the possibility of demand destruction. However, close examination of Box 26 suggests that industrial use fell during the period 1997-1999, when natural gas prices fell, and that subsequent consumption was consistent with the 1997-1999 trend. Indeed, for most sectors, the 1997-1999 pattern was continued into the period 2000-2004, when prices were rising steeply. Only natural gas use for electricity generation showed departure from the earlier trend, in 2003 and 2004. This exceptions suggests that price increases may have a stronger effect when consumption is increasing than when it is declining.

The most important conclusion to be drawn from Box 26 is that large increases in natural gas prices¹⁹⁹ had little impact on consumption, at least in the short term, in spite of possible opportunities for demand destruction, for fuel switching in the commercial sector, and for conservation in all sectors.

The North American natural gas case deserves further examination as an illustration of both the peaking of production of a fossil fuel and the responses to the peaking of produc-

Box 26. Annual U.S. per-capita end-use of natural gas, by sector (left scale) and average annual 'city gate' prices for natural gas (right scale)



Source: U.S. Energy Information Administration

tion. There may be lessons to be drawn about the nature of a peak in world oil production and about how various sectors may behave in response to the peak.

As for the use of natural gas as a transport fuel, a reasonable, brief conclusion is that it may have short and medium term potential as a transport fuel, and as a source of hydrogen, but the longer-term impact will not be significant unless what may be immense amounts of the fuel in methane hydrates can be exploited.

3.5. Coal liquefaction

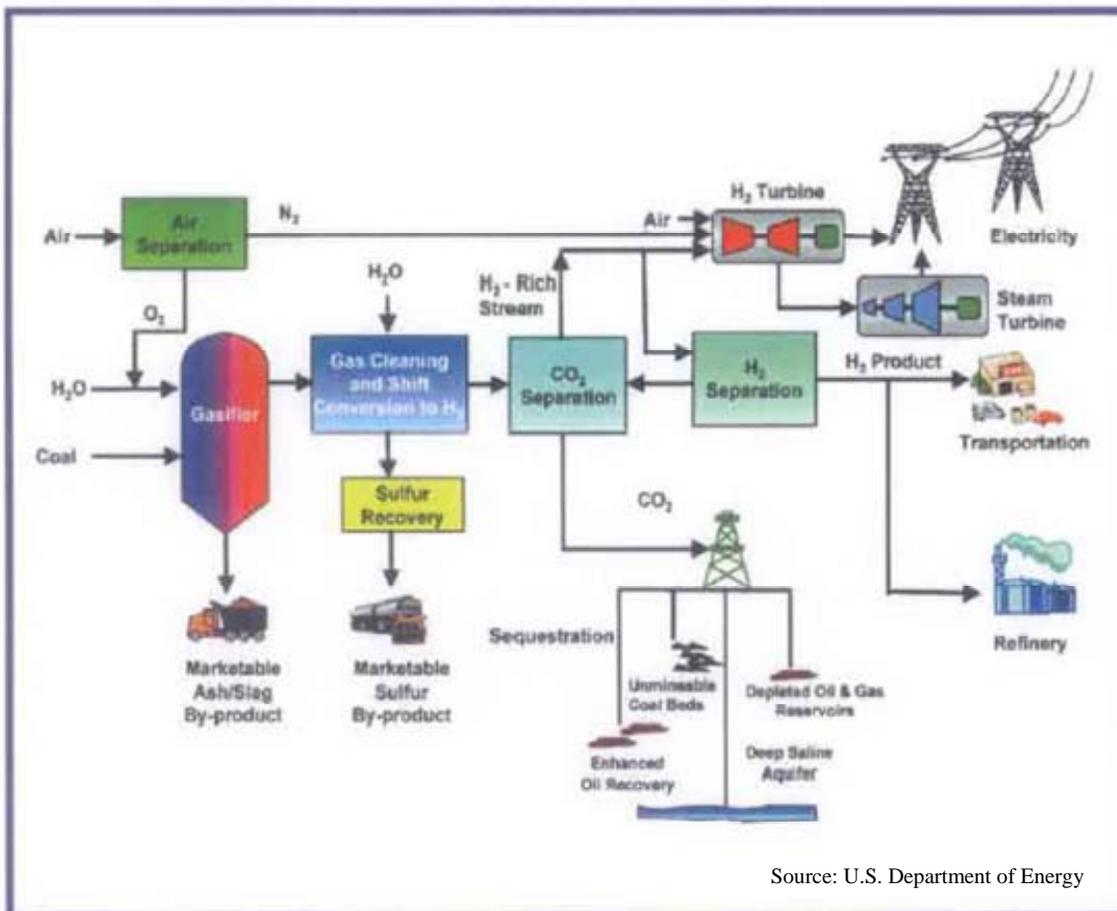
In the late 19th century and beyond, coal was *the* main transport fuel, burned in steam engines (*external* combustion engines) that powered trains and ships with remarkably low efficiency. Steam engines converted only a tenth of the energy in their fuel into kinetic energy.²⁰⁰ From about 1860 the fuel was chiefly coal, which has only half the energy content per kilogram of oil (although almost twice that of wood, used widely before 1860).²⁰¹ Thus, much of the work done by steam trains comprised pulling around large amounts of fuel. Diesel train engines—usually diesel-electric, but also diesel-mechanical and diesel-hydraulic—took advantage of oil's higher energy content and diesel engines' higher efficiency. They reduced the weight of fuel to be carried by as much as a factor of 10, allowing for much easier fuel delivery. Moreover, they produced much less pollution.

Coal remains plentiful and relatively inexpensive, although prices have more than doubled in the last year with growth in demand by China.²⁰² The primary use of coal in Canada and elsewhere is for generation of electricity through the production of steam that powers turbines. Worldwide this process produced 39 per cent of electricity generated in 2002, 46 per cent in North America, and 77 per cent in China.²⁰³

As well as being burned in open fires and furnaces, coal was heated in the absence of air to provide coal gas, also known as ‘town gas’, a mixture of methane, hydrogen, and carbon monoxide.²⁰⁴ Coal gas was used widely for lighting and heating, until replaced by electricity and natural gas. It could be used directly as a vehicle fuel, in ICEs or in fuel cells.²⁰⁵ Indeed the first device called a fuel cell—not the first fuel cell—used coal gas as a fuel.²⁰⁶

Conversion of coal to a liquid transport fuel involves application of the Fischer-Tropsch process, applied extensively in Germany in the early 1940s and in South Africa in the 1950s-1980s.²⁰⁷ As with the production of liquid fuel from natural gas, the costs of oil from coal are sensitive to the price of the feedstock, and the effective oil price rises more or less in step with the actual coal price.²⁰⁸ Coal prices vary enormously, in time, in place, and according to the quality of the coal.²⁰⁹

Box 27. Simplified flow diagram of function of proposed FutureGen plant



Source: U.S. Department of Energy

China's first coal liquefaction plant is expected to begin operation in 2007, eventually producing five million tonnes of oil and oil products annually, about two per cent of China's present consumption. Current plans are to have coal liquefaction meeting as much as 10 per cent of China's oil needs.²¹⁰

However effected, production of oil from coal is a heavy generator of carbon dioxide. Reduction in these GHG emissions, through sequestration, could add additional cost to the process, perhaps US\$10/barrel. The burning or other conversion of coal also produces numerous locally acting pollutants, notably nitrogen oxides, sulphur dioxide, and particulate matter. These too can be reduced at a cost.

In 2003, the U.S. government announced a \$1-billion program, FutureGen, to develop a near-zero-emission plant that will generate electricity and produce hydrogen from coal, with combined output equivalent to 275 megawatts (see Box 27).²¹¹ Such a process could also be used to produce oil useful as a transport fuel.

Although coal is plentiful relative to other fossil fuels, the amounts are finite. Current estimates assume availability of about 900 billion tonnes, of which about 275 billion tonnes are in North America. Presently, about 0.5 per cent of mineable coal is used annually, leading to the observation there is about 200 years of coal left.

If coal were to replace half of oil use and half of natural gas use, coal use would more than double, with a corresponding shortening of the period of availability.²¹² As in the cases of oil and natural gas, production limits could be reached when about half of ever-available coal has been mined. For the U.S.—and possibly North America and the world—this has been estimated to be near the year 2050.²¹³

3.6. Biofuels

As for carbon-based liquid fuels made from natural gas and coal, fuels made from biological material—biofuels—offer the prospect of continued use of familiar ICEs, with the additional possibility of a renewable source. A recent review of biofuels by the International Energy Agency concluded the following:²¹⁴

- Except in tropical countries where cane sugar and low-cost labour can be used to produce ethanol by fermentation and distillation, notably Brazil, the cost of production of biofuels is up to three times that of petroleum fuels.²¹⁵
- Costs could fall significantly with the commercialization of enzymatic production from lignocellulosic feedstock, expected in Canada, the world leader in this technology, in 2006.²¹⁶ Other processes that could reduce costs include gasification and pyrolysis.
- The environmental advantages of biofuels use can be considerable, especially with respect to GHG emissions, and would be enhanced with use of lignocellulosic feedstock. Production of one litre of biofuel requires the input of 0.00-0.70 litre of petroleum, to heat materials, power machinery, make fertilizers, and provide transport, with production of ethanol from grain requiring the most input and production of ethanol from

sugar cane requiring the least input (although the lignocellulosic feedstock process could be better).

- Use of biofuels can be limited by land requirements. In the U.S. and the EU—data are not available for Canada—replacement of five per cent of gasoline and diesel would require use of 20 per cent of available cropland.

Thus, biofuels—chiefly ethanol as a gasoline substitute and biodiesel—may have considerable scope for use in a regime of high-price transport fuels. They could also fuel or partially fuel some aviation.²¹⁷ However, their use is also severely criticized on several grounds. This is the opening paragraph of a recent major review:²¹⁸

It is not uncommon for the researchers involved in biomass processing for fuels to claim that there are billions of tonnes of “biowaste” out there, ready to be picked up each year, and processed, providing – in effect – an almost free, abundant and environmentally benign source of energy for humanity. We will argue that ecosystems (the Earth Households) are the intricately linked webs of life that know of no waste. Therefore, “biowaste” is an engineering classification of plant (and animal) parts unused in an industrial process. This dated human concept is completely alien to natural ecosystems, which must recycle their matter completely in order to survive. Excessive “biowaste” removal robs ecosystems of vital nutrients and species, and degrades them irreversibly.

The reviewers conducted a thermodynamic analysis of a typical tree-biomass-for-energy plantation combined with an efficient local pelleting facility. They concluded, “The highest biomass-to-energy conversion efficiency is afforded by an efficient electrical power plant, followed by a combination of the Fischer-Tropsch diesel fuel burned in a 35%-efficient car, plus electricity. Wood pellet conversion to ethanol fuel is always the worst option.”

These reviewers said nothing about production for transport purposes of biogas, i.e., a mixture of methane and carbon dioxide produced by anaerobic digestion of organic material, often waste material such as pig manure. Upgraded by removal of the carbon dioxide, and then compressed, biogas is used increasingly as a transport fuel, alone or mixed with natural gas. The west of Sweden is a focus of use of this fuel, which is available at 18 filling stations and is used by several thousand vehicles.²¹⁹

Biofuels may offer the only opportunity for sustainable aviation, i.e., aviation that uses renewable fuels. Work in Brazil has concerned the feasibility of using vegetable kerosene in jet engines and ethanol in aircraft piston engines.²²⁰

Chapter 4. Fuels for electric drives

4.1. Hydrogen

Availability of one or more of the just-discussed three main alternatives to oil—carbon-based liquid fuels produced respectively from natural gas, coal, and biomass—would allow transport to continue in pretty much the same way it does now, albeit more expensively. This section provides the first discussion of a potential radical departure from present ways of doing things.

In the evolution of fuel use, there has been a progressive replacement of carbon by hydrogen. The hydrogen/carbon ratio is higher in coal than in wood, higher in oil than in coal, and higher in natural gas than in oil. The ultimate step would be movement to pure hydrogen as a transport fuel. The main advantages would be its suitability as a fuel for fuel cells and the lack of carbon dioxide emissions from the combustion of hydrogen. The main disadvantages would be that hydrogen can be affordably produced only from fossil fuels, and that this extremely light, penetrating, and explosive gas is difficult to store and distribute, and especially difficult to carry in vehicles.

Use of hydrogen as a fuel for ICEs has been favoured by one major automotive manufacturer, which is already winning performance prizes with prototype vehicles.²²¹ The rest of the industry and many governments appear to favour evolution towards transport systems featuring fuel-cell-powered electric motors.²²² These options were discussed in Chapter 3. For the moment, the focus is on production and distribution of hydrogen.

Today, almost all hydrogen is produced from natural gas,²²³ which already has production constraints and will have more (see Section 3.4).

Hydrogen could be produced from coal, as discussed above in respect of the FutureGen program,²²⁴ and indeed from any fossil fuel, but always with a requirement to handle the high levels of carbon dioxide and other emissions.

Perhaps the simplest way to produce hydrogen is by electrolysis, which involves no more than passing an electric current through water and collecting the gas that appears at the cathode. Although simple in concept, in practice electrolysis is generally an expensive method of hydrogen production, according to the cost of the electricity.²²⁵ It is also an inefficient process, especially if the hydrogen produced from electrolysis is to be used for generating electricity, as elaborated in Section 2.7 above during the discussion of fuel cell-powered vehicles.

Hydrogen supply is thus a matter of fossil fuel availability or of electricity supply. There are also the key matters of distribution and storage.²²⁶

In conclusion, there are severe challenges in realizing the frequently articulated dream of a hydrogen economy, even without considering the particular challenges posed by fuel cells, discussed in Section 2.7.

Nevertheless, the hydrogen vision remains attractive because it could allow a clean break from fossil fuels, while maintaining the allure of independent mobility with long distances between refills.

4.2. Nuclear energy

Nuclear fission is the world's second most important non-fossil-fuel source of added energy, accounting for seven per cent of total primary energy in 2002. Sources in order, with shares of total energy supply, were oil (36 per cent), coal (23), natural gas (20), biomass and waste (11), nuclear (7), and other non-fossil-fuel sources (3).²²⁷

Nuclear fission can be used to produce steam that drives a turbine, as is used to provide motive power for some submarines. More often, such turbines are used to generate electricity, which can fuel vehicles directly or produce hydrogen for vehicles through electrolysis of water. In theory, nuclear energy could be used to produce hydrogen directly through thermochemical water cracking.

Nuclear energy was embraced in the 1950s-1970s in Ontario and elsewhere because it offered the prospect of low-cost pollution-free generation of electricity. The International Energy Agency reported recently that compared with *existing* coal, natural gas, and wind plants, nuclear plants in operation provide the lowest cost of generation.²²⁸ However, IEA had reported last year that *new* nuclear plants would provide the most expensive electricity when compared with new generation based on the other fuels.²²⁹ The discrepancy between the reports is confusing and may exist because different factors were taken into account.

One factor is liability for catastrophic failure. Had this not been limited by statute in all jurisdictions where nuclear plants were constructed, costs might never have appeared reasonable. Insurance against the effects of such failure may have been prohibitively expensive.²³⁰

Another item that may not have been properly factored into the cost of electricity generation from nuclear energy is the cost of radioactive waste disposal. This cost seems to be difficult to estimate. The issue is topical, although not so much in Canada as elsewhere, notably in Sweden and the U.S.²³¹

Expanding nuclear energy is being promoted, even by some environmentalists, as the only effective means of reducing risks from climate change while providing the secure and reliable source of energy needed to retain civilization.²³²

How much nuclear capacity might have to be expanded can be evident from the distribution above. Replacing half of the fossil-fuel energy supply would require about a six-fold increase from present capacity. This would raise present installed capacity worldwide from about 360 gigawatts (about a tenth of the total electricity generating capacity)²³³ to over 2,000 gigawatts, equivalent to adding 1,500 nuclear reactors each rated at 1,200 megawatts, or about one a week indefinitely, assuming a 30-year life for each reactor.

An undertaking of this scale would raise at least four concerns: (i) whether there would be enough fuel, fossil or otherwise, to construct the reactors; (ii) whether there would be enough fuel to operate the reactors; (iii) whether proliferation of nuclear power production to this extent would pose a security threat, and (iv) what would be done with the radioactive waste.

On the second point, the matter of uranium reserves is complex, and reference is made to Box 28,²³⁴ which gives the impression that uranium supplies are not an issue. If uranium is indeed essentially inexhaustible, perhaps it should be regarded as a renewable source of energy.

It's the fourth of the above four points that raises the most concern and underpins most opposition to nuclear power. An industry-led body, the Nuclear Waste Management Organization, has been established under federal law to provide for discussion of nuclear waste disposal in Canada. It has proposed "centralized containment and isolation of the

Box 28. On uranium reserves

Since uranium is ubiquitous and plentiful in the earth's crust, its availability is determined almost entirely by the willingness to find it. Thus, while today's low uranium cost equates to about 50 years of assured resources (3.1 Mt) using conventional reactors at the current usage rate, a doubling of the market price increases this time roughly ten-fold. In all, conventional estimated resources account for about 250 years' supply (16.2 Mt) at the current consumption rate. This does not include advanced uranium-extraction scenarios (phosphate deposits accounting for 22 Mt, seawater accounting for up to 4000 Mt) that require 10-15 times the current market price.

Current reactor technology is a meaningless yardstick in such scenarios, however, due to its relatively inefficient use of resources. Reactor development has always assumed the need for advanced fuel cycles, even after the discovery of significant uranium deposits around the world allowed a levelling off of the development curve. As low-cost uranium resources dwindle, more fuel-efficient reactors will find a market.

The realm of current technology does permit a significant extension of resources, particularly if high-converter technology like CANDU is exploited to its fullest potential. A 40% improvement in fuel usage is achieved just by replacing an LWR with a CANDU reactor. Alternatively, recycling spent LWR reactor fuel in a CANDU reactor extracts 50% more energy from the original uranium supply. This can be achieved either by extracting the left-over fissile material (uranium and plutonium) from the LWR fuel, or by simply re-engineering the spent fuel to fit into a CANDU reactor without reprocessing (i.e., the DUPIC fuel cycle).

Even more available than uranium in the earth's crust is thorium (roughly three times the abundance), which can be used in conventional reactors to breed uranium fuel (U-233). Once-through thorium fuel cycles in CANDU, for example, can achieve near-breeder status and almost render uranium availability an irrelevant issue.

Finally, the ultimate in efficient resource usage is the Fast Breeder Reactor (FBR), a technology that creates more fissile fuel than it consumes. Uranium resources can be extended by a factor of 60 - 100 with the widespread use of breeder technology, although the economics will probably first lead to a hybrid arrangement where FBRs synergistically feed high-converter thermal reactors like CANDU.

Source: Whitlock J, *Canadian Nuclear FAQ*

used fuel in a deep geologic repository in suitable rock formations, such as the crystalline rock of the Canadian Shield or Ordovician sedimentary rock”.²³⁵ Also of concern is the third point, both the possibility of attacks on nuclear plants and the use of nuclear material for weapons.

Sweden has perhaps gone the farthest towards phasing out a substantial nuclear capacity with a 2002 law mandating replacement by renewables. But little has been done towards implementing the law or is even planned, and nuclear plants continue to produce about half of the country’s electric power.²³⁶

Nevertheless, for transport purposes, nuclear power generation could be massively expanded to produce hydrogen from electrolysis or to power vehicles directly, by charging batteries or other storage devices in vehicles or by continuous powering of vehicles via a tether linking them to an electrified wire or rail.

As noted above in Sections 2.7 and 4.1, production of hydrogen from electricity generated by nuclear energy could be a relatively inefficient approach as there would be energy losses in the production and distribution and then more in the use of the hydrogen. Use in fuel cells to drive electric motors would be more efficient than use in ICEs, but in either case there would be much less wastage if the electric power were applied directly to the electric motors. Tethered vehicles would use the power more efficiently than battery vehicles because there would be no losses as the electricity moves into and out of storage and no additional energy use to move heavy batteries around. However, tethered vehicles, discussed here in Section 2.8, have less flexibility than vehicles that carry their own fuel.

4.3. Renewables, including wind, solar, tide, geothermal, and hydroelectric

As well as the previously discussed form of renewable energy, biofuels, wind energy is attracting considerable attention, in this case as a means of electricity generation rather than as a source of liquid transport fuels. (Biofuels—solid, liquid or gas—could also be used to generate electricity.)

Worldwide, wind power is the fastest growing source of electricity generation.²³⁷ Its costs are competitive with the upper ranges of more conventional generation methods. The ‘fuel’ it uses, wind, is totally renewable. Impacts are relatively small, with bird deaths appearing to be the main problem, especially for turbines with smaller, faster blades. There are aesthetic issues, with perhaps as many people liking their appearance as disliking it. There are also concerns that large-scale wind power could alter the local and global climate by inducing atmospheric turbulence.²³⁸

The main disadvantage of wind power is its intermittency, a disadvantage shared with solar,²³⁹ tide,²⁴⁰ and wave power.²⁴¹ According to the operator of the electricity grid for much of Germany, the world leader in wind energy use, traditional power station capacities must be maintained as so-called ‘shadow power stations’ at a total level of more than 80 per cent of the installed wind energy capacity.²⁴² An alternative would be to reduce reliance on uninterrupted electricity, for example, by using devices powered by recharge-

able batteries, such as laptop rather than desktop computers and battery drills rather than drills that need to be continuously plugged in.

Geothermal power is usually continuous. Hydroelectric power is usually continuous and can be often be stored as water behind a dam.

A recent review of renewable energy applications in Canada concluded, “Though Canada has huge prospects for low-impact renewable energy technologies, it is falling behind most industrialized nations in the expansion of these technologies due to a lack of supporting structures and the absence of supporting government policies and initiatives.”²⁴³ It should be noted, however, that Canada is the world leader in installed hydroelectric capacity, which uses a renewable resource although not always in a low-impact manner.

Current Canadian electricity generating capacity is about 110 gigawatts, almost two thirds of which is hydroelectric. According to Natural Resources Canada, renewable energy sources could provide or displace a similar or larger amount of capacity at or near current costs of production, the major share coming from new large-scale hydroelectric sources.²⁴⁴ Not included is the huge potential for electricity production from solar photovoltaic sources, whose costs may approach current generation costs within a decade or so. The review noted in the previous paragraph suggests that applying photovoltaic panels to every appropriate building surface could meet all residential and commercial electricity requirements, which presently comprise about 55 per cent of total use.²⁴⁵

The present authors believe that a feasible and necessary target for Canada would be to meet at least 50 per cent of *all* its energy requirements from renewable resources by 2031. As noted, this is already the case for electricity production. As the need for electricity expands, particularly with massively increased use for transport, maintaining most electricity production from renewable resources will be a challenge, even if nuclear generation becomes considered ‘renewable’. Production from wind, sun, waves, tides, and geothermal sources, and perhaps biofuels, will have to be expanded enormously. This expansion will have to go hand-in-hand with remarkable efforts to improve energy efficiency in all sectors, notably transport, and to offset electricity use where possible.²⁴⁶ The alternative will be to suffer crippling increases in fossil fuel prices and potentially catastrophic changes in climate.

Chapter 5. Socio-economic drivers of transport activity

5.1. Planning ahead and changing core values

The benefits of comfortable travel and effective goods movement hardly need explaining; they are touched on in Box 29.²⁴⁷ What needs to be explained is why in seeking these benefits humans seem to be so improvident, particularly with regard to fuel for transport, but also to many other kinds of energy-intensive activity. Our preoccupations are mostly with the present. The pace-setting European-America culture seem to have lost—and perhaps have never had—a strong interest in the well-being of generations ahead.

Many of Canada's First Nations have had a tradition of looking ahead in this way. The Royal Commission on Aboriginal Peoples reflected the tradition in the title of its massive

Box 29. A brief history of transport

Travel and the movement of freight have been part of human experience since the migrations of our distant ancestors out of Africa, first to Europe and Asia and then to Australasia and the Pacific islands. Among the most remarkable journeys have been those to the Americas: from Asia in the millennia before history—across what is now the Bering Strait to as far south as Terra del Fuego—and from Europe and Africa during the last millennium and perhaps before.

Societies across the world have prospered in military conquest, trade, and economic progress to the extent they have rationalized the movement of people and freight. Over the years, effective transport brought advantage to numerous peoples: the Phoenicians, Romans, Mongols, Venetians, Incas, Dutch, British, and Americans, among others. During the last 200 years, the links between transport and economic progress have become especially tight.

Until the 19th century, travel everywhere was uncomfortable, dangerous, and enormously time-consuming. Freight movement posed even greater difficulties. Rail transport made the difference. The linking of two earlier inventions—wheels on smooth iron rails and the steam engine—allowed widespread motorized transport across land, and the beginning of a new era in the mobility of people and goods. Also important was the linking of the steam engine to the paddle wheel and propeller to provide motorized water transport.

Rail transport began to give way to road transport in the first part of the 20th century, although the main expansion in the use of road vehicles has occurred since 1945. Air transport arrived soon after motorized road transport, allowing high-speed travel over great distances and ready access to remote places. Ocean freight still dominates the carriage of products and raw materials.

Motorized transport has facilitated and even stimulated just about everything now regarded as progress. It has helped expand intellectual horizons and deter starvation. Comfort in travel is now commonplace, at a level hardly dreamed of in former years even by royalty, as is ready access to the products of distant places.

The growth of personal road transport—chiefly the automobile—has been closely associated with two of the major phenomena of the twentieth century: growth in material well-being and extension of voting rights. Ownership and use of an automobile—usually the most expensive of consumer purchases—have assumed in rich countries the status of democratic rights. As tokens of passage into adulthood, they can be more important than the ability to vote.

Gilbert R, *Encyclopedia of Global Environmental Change*

final report: *For Seven Generations* (1997). In Volume 2 of the report, there is mention of the Kaianerekowa—Great Law of Peace—of the Haudenosaunee (Iroquois) Confederacy, as the most frequently cited example of traditional Aboriginal law. It included the following:²⁴⁸

The lawmakers, in weighing any decision, must cast their minds seven generations ahead, to consider its effects on the coming faces. The lawmakers must consider the effects of each decision on the natural world.

Williams and Nelson (1995) in Royal Commission on
Aboriginal Peoples (Vol. 2, Ch. 3, Sec. 1.2)

Two recent popular books have reflected on our society's apparent inability to plan well ahead in the context of discussion about what enables successful management of profound change. Jane Jacobs proposed that societal resilience depends upon the strength of five "stabilizing pillars" that sustain the cultural practices essential to successful adaptation.²⁴⁹ Jared Diamond also highlighted the value of long-term planning for survival, but proposed in contrast that societies are resilient to the extent they reconsider and replace core values.²⁵⁰

We lean toward Diamond's view that our survival depends not only on engaging in long-term planning but also on the extent to which we are able to replace certain core values. One such core value is that moving people and goods farther and faster in ever-increasing amounts is inherently desirable, a value manifested in the 'predict and provide' paradigm that has inspired transport policy for at least three generations. Canadians' response to oil constraints may well have to involve replacement of this core value with another to be determined.²⁵¹

Meanwhile, as in advance of all paradigm shifts, there is unwillingness to embrace such replacement. Opinion-formers' perspectives on the future of transport are rooted in continuation of present trends, with a focus on identifying and making whatever adjustments in the form of technical fixes may be needed to allow things to continue as they are. The prevailing view is that challenges, including the challenge posed by the end of cheap oil, can be adequately faced by new technology, even if the challenge is imminent and the proposed fixes are far from implementation. One purpose of the present paper is to encourage and enable a broader consideration of alternative futures.

5.2. Population growth drives transport energy use

There are numerous particular factors that contribute to our transport dependence and thus our oil dependence. A significant factor in Canada is population growth, fuelled by immigration.

Population growth gives Canada the hardest task among all the ratifiers of the Kyoto Protocol on climate change. We agreed in 1997, and ratified in 2004, to reduce GHG emissions to six per cent below our 1990 level. Western Europeans agreed to an eight-per-cent reduction. Our population is set to grow by 22 per cent between 1990 and 2010; their population by seven per cent. Thus, Canada's six-per-cent reduction requires a 23-per-

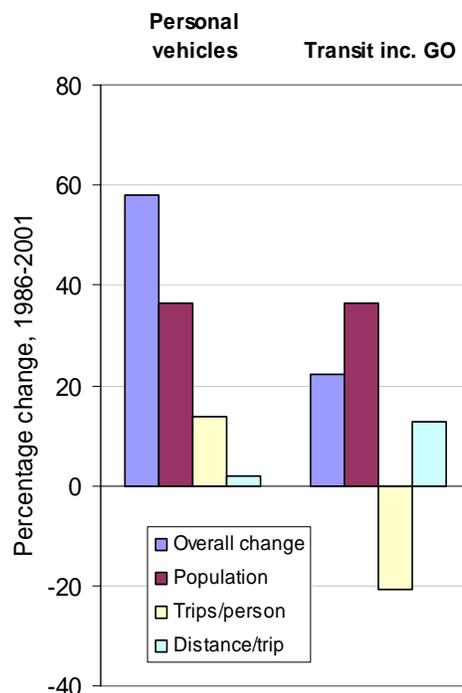
cent *per capita* reduction, while Europe’s eight-per-cent reduction requires a considerably lesser per-capita reduction, by 14 per cent.

Box 24, discussed in Chapter 3, shows that Canadian oil use per capita has been rising since the early 1990s. Box 6, discussed in Chapter 2, shows that freight movement by truck has been the major driver of this increase. As well as disaggregating data on oil consumption, Box 6—unlike Box 24—provides *per capita* data, and allows the observation that oil use for the movement of people has been increasing at close to the rate of population growth (actually just slightly higher: 15 vs. 13 per cent across the period 1990 to 2002).

Box 30 provides disaggregation of contributing factors to growth in the movement of people—person-kilometres travelled—within Canada’s largest urban region,²⁵² where the rates of growth of both road traffic and population have been much higher than the national average. The left-hand set of bars shows that the 58-per-cent growth in travel by personal vehicle (cars, SUVs, etc.) between 1986 and 1991 resulted from three multiplicative factors: a 37-per-cent growth in population, a 14-per-cent increase in the number of trips per person, and a two-per-cent increase in trip length. The right-hand set of bars represents changes in travel by transit, both local transit and regional transit (the GO system). Here the major decline in trips per person substantially offset population growth and increase in average trip length. Of all motorized trips in 2001, about 87 per cent are represented by the left-hand set of bars and 13 per cent by the right-hand set of bars.

The data on travel within the Toronto region in Box 30 suggest that although population growth is the major contributor to growth in travel, other factors (more trips per person

Box 30. Contributing factors to growth in the movement of people in the Toronto region



and longer trips) played a more important role in travel growth there than for Canada as a whole. Indeed, because the Toronto region contributes roughly a third of Canada's population growth, and a higher share of growth in travel, the suggestion arises that the factors of increased number of trips per person and increased trip length may be specific to the region and perhaps other large urban regions.

Population and traffic growth in large urban regions occur mainly in their outer suburbs, which is where growth in transport dependence occurs. This is because they are generally built at low densities of homogenous uses. Residences are at a distance from regular destinations, making walking and bicycling impractical for most trips. The low densities, whether for outer-suburban residential, commercial or industrial development, make transit infeasible, resulting in increases in trips by personal vehicle per person and in average trip length. To the extent population growth stimulates development at the periphery of large urban areas, it is 'locking in' dependence on automobile use that will become dysfunctional when oil constraints occur.

Canada's population growth thus appears to increase transport energy use in two ways. First, travel per person and related fuel use are relatively constant, and so more people means more fuel use. Second, the population growth occurs mainly in places that impel higher-than-average use of personal vehicles.

As well as growth in the whole population, there are also changes in the composition of the population that will have a bearing on transport activity. The gradual increase in the median age means that the share of the population of driving age increases. Another factor is the larger number of young people living in low-density suburbs, who almost automatically begin driving at age 16, unlike their inner-city counterparts. Yet another factor is the growing wealth and fitness of older people, and a greater inclination for them to drive.

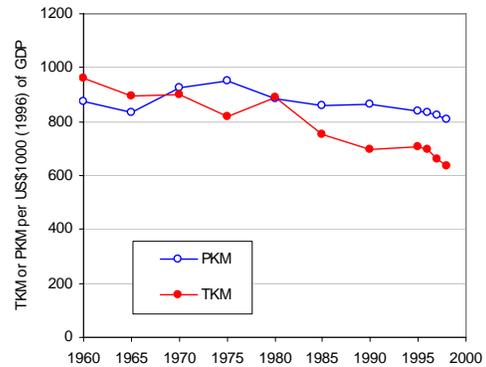
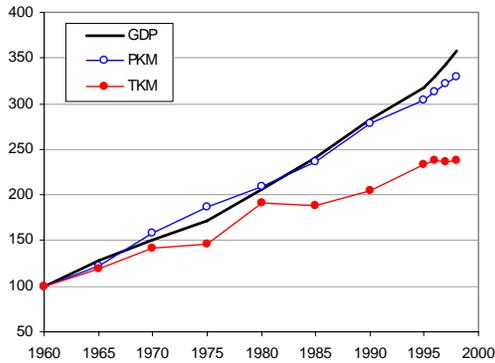
5.3. Transport and economic development

More than the movement of people, the movement of freight in Canada reflects the growth in economic activity. This is evident from Box 31,²⁵³ which shows a stronger association with GDP for the movement of freight, in contrast to both the U.S., where the movement of people is more strongly associated with GDP, and the European Union (EU15), where both are more strongly associated (although with freight activity per unit of GDP occurring at much lower levels). The relationships for Canada, compared with the U.S., likely reflect our greater dependence on trade and the smaller share of our economy comprising information technology and other service-sector activities that do not require or generate heavy material flows.

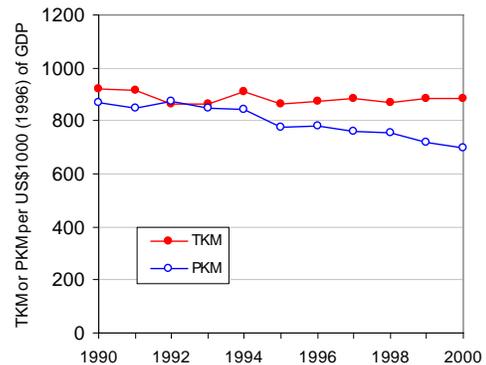
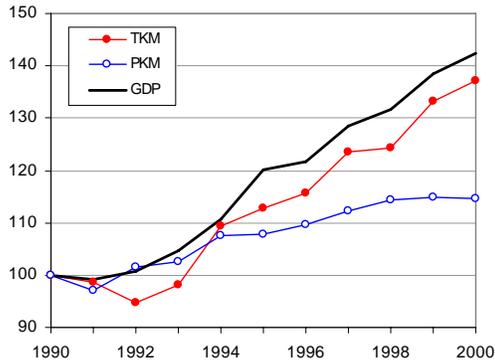
Box 31 highlights the importance of freight movement for Canada and thus signals the strong challenges that will be posed by oil constraints. Reducing oil use for trucking in particular in advance of oil constraints could thus become a matter of protecting economic activity from the effects of the constraints. Accordingly, application of current revenues from high oil prices to ways of reducing energy use for freight transport could

Box 31. Normalized transport activity and GDP (left-hand panels) and transport intensity (right-hand panels) for the United States, Canada, and the European Union, various years)

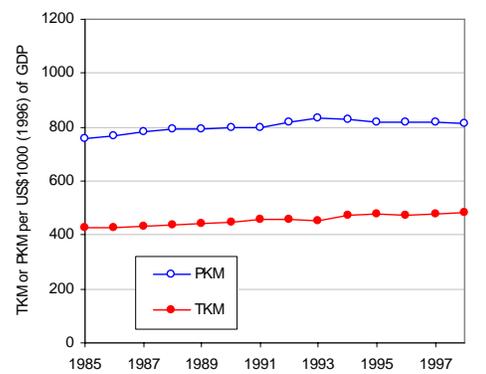
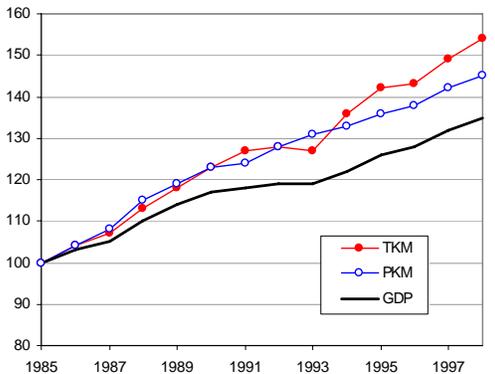
UNITED STATES



CANADA



EUROPEAN UNION



Source: Gilbert & Nadeau

be seen important investment in Canada's economic future. Some pointers towards this end are provided in Chapter 6.

Also to be remembered is the contribution to freight and other commercial transport made by reducing the number of private vehicles on the road, including through the provision of good public transit. In Singapore, where private vehicle ownership is rationed and

transit service is excellent, restrictions on private-vehicle use were originally introduced to facilitate freight movement. Now, improvement of the environment is also an objective.

The causal link between transport and economic development is usually thought of as being that the former contributes to the latter: the better the transport systems the more the economy can flourish.²⁵⁴ However, the opposite effect has also been held out as predominant: namely that economic activity is the main driver of transport activity.²⁵⁵ The fall in transport energy use between 1990 and 1991 shown in Box 6 likely reflected rather than caused the ongoing economic recession. In reality, both effects are likely important: transport both facilitates and reflects economic activity.

If Canada's economy is not protected from higher oil prices, economic activity could decline with a corresponding fall in transport activity. This would be additional to from the direct effect of higher prices on transport activity discussed in the next section.

Higher oil prices could well adversely affect the economies of other countries, particularly that of the U.S. because of its high dependence on oil, growing dependence on imported oil, and low taxes on oil products. Where taxes are low, the cost of oil is a larger component of oil prices and exposure to crude oil prices is consequently higher. Because so much of Canada's economy is linked through trade to that of the U.S., a recession there could depress economic activity in Canada. Moreover, Canadian exports to the U.S. could be further reduced because an effect of higher oil prices could be to depress the U.S. dollar in relation to the Canadian dollar, especially if oil becomes traded in euros.²⁵⁶

Reduced oil consumption resulting only from reduced economic activity would be an unwelcome way of addressing the disproportionate increase in use for freight transport illustrated in Box 6. It would amount to a 'hard landing' of the kind noted in Chapter 6.²⁵⁷

5.4. Transport prices and transport activity

So far, a rise in oil prices consequent on an imbalance between production and potential demand for oil has been discussed in terms of its impact on discovery and production of oil and of substitutes for oil, and on national economies. Equally or more important could be the impact of high prices on consumption of oil, particularly oil for transport.

The main challenge in reporting for present purposes on the price elasticity of demand—i.e., how much transport activity changes when fuel prices change by 10 per cent—is that available data concern small changes and conclusions from them may not be relevant to the larger price increases that could happen before 2030.

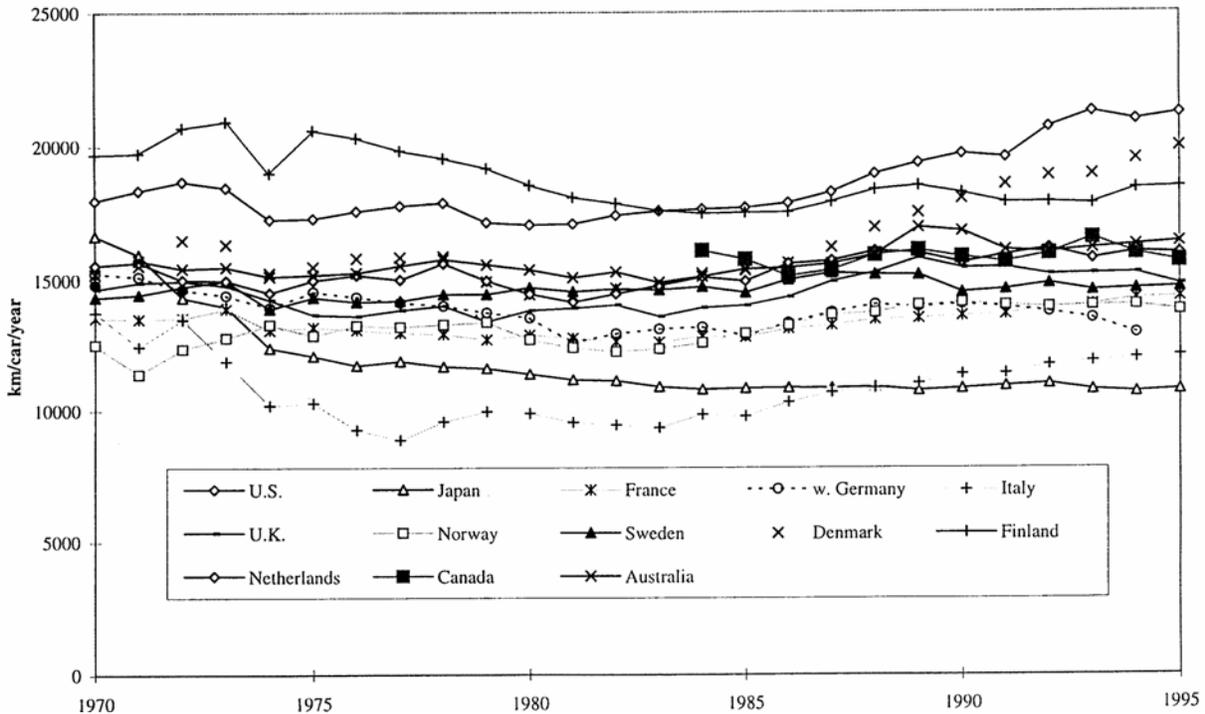
The available evidence is consistent on two points.²⁵⁸ The first is that elasticities are generally low, meaning that a 10 per cent increase in fuel price would produce much less than a 10 per cent reduction in transport activity. The second point is that long-term elasticities are higher than short-term elasticities. This means either that people's travel behaviour adjusts to higher fuel prices but takes time, or that the main response to higher

prices is the purchase of more fuel-efficient cars than might otherwise be bought, or both. Preliminary indications of the impact of recent fuel price increases are that they are having little impact on the amount of driving but a considerable impact on which vehicles are purchased.²⁵⁹

Some kinds of transport are more sensitive to price than others. For example, as noted in Section 2.11, the ticket price elasticity of international long-haul tourism travel by air could be almost four times that of such travel for business purposes. This means that a ticket price increase, and by extension, a fuel price increase, could have about four times the effect on tourism as on business travel.

An important consideration is whether it is more effective to restrict automobile use directly—through price or in another way—or less directly through limits on or deterrents to ownership. Ownership is an evident pre-condition for most vehicle use, but it may also be a driver of use. Within a country, kilometres driven per vehicle is relatively constant from year to year, as illustrated in Box 32.²⁶⁰ Thus, total vehicle-kilometres driven is closely associated with the number of vehicles on the road. It is as if possession of a car causes use of it. Accordingly, restrictions on car ownership, as practised in Singapore (by a system of auctioned entitlements) and in Tokyo (by requiring an owner to have an authorized private parking place) can be as or more effective than deterrents to use, through high fuel prices or other imposed costs of operation. An interesting case in point may be the role of high insurance costs, which appears to have caused owners to lay up vehicles in Atlantic Canada and may serve as a restraint on car ownership and use by young people.

Box 32. Kilometres driven annually per automobile, various countries, 1970-1995



Source: Schipper

5.5. Path dependence

This term refers to systems and processes that ‘lock in’ particular ways of doing things and thus present barriers to change.²⁶¹ The most-cited example is the QWERTY keyboard, which is far less than optimal for ease and speed of use but survives because a different key arrangement would require much re-learning. One instance of path dependence in connection with transport has already been mentioned. It is the present practice of accommodating Canada’s population growth by developing sprawling low-density suburbs that ‘lock in’ particular transport patterns and make change difficult.

At least as important are the ‘lock-ins’ resulting from the location and practice of business that have contributed to the disproportionate increase in fuel use for freight transport illustrated in Box 6. Refinements of supply chain management, particularly during the 1990s, led to spatial fragmentation of production facilities and substitution of frequent deliveries for warehousing, both of which contributed to much increased freight transport activity.²⁶² The increased activity comprised both longer trips, as the production of elements of a product became consolidated in separated facilities and more frequent trips to meet ‘just-in-time’ requirements. Data for the U.S. suggest that each component has contributed almost equally to the increase in truck vehicle-kilometres.²⁶³ Adding to the transport burden has been outsourcing of components to take advantage of lower-cost manufacturing in distant developing countries.

The overall result has been massive reorganization of business practice that has locked in dependence on transport particularly truck transport. There has also been a ‘lock in’ of consideration of the future of freight transport, which is almost entirely characterized by schemes and strategies to accommodate large increases in freight transport activity. A partial exception is a Dutch scenario study of freight transport futures that included a “sustainable growth scenario” in which “transport will grow modestly or not at all (for certain modes) ... with rail and water transport taking over a share of road and air transport”.²⁶⁴ This was analyzed along with three other scenarios in which substantial growth in transport activity would occur. The differences among the scenarios were to be achieved by government action. Oil availability was not a factor in this scenario construction.

Chapter 6. Energy and transport: A soft or a hard landing?

How have Canadians and other people allowed themselves to become so dependent on a resource—oil—that has an uncertain future and no obvious replacement? What are the prospects for soft landing when the next, perhaps the last, oil shock comes? ‘Soft landing’ means that the world crude oil price rises—even to the US\$320 per barrel of crude oil contemplated by the Brookings Institution (see Box 25)—and yet Canadians experience little adverse impact. What could be done to ensure that there is a soft rather than a hard landing, which at its extreme—a ‘crash landing’ rather than merely a ‘hard landing’—would disconnect large numbers of Canadians from essential social and physical support and precipitate economic depression and social unrest on a scale not seen since the 1930s?

These important questions are mostly beyond the scope of this paper. They warrant a separate paper of similar scale. However, the questions are given brief answers here to round out the present treatment of energy and transport futures and provide a starting point for further discussions.

6.1. Preparing for a soft landing

What can be done to prepare for the end of cheap oil? The best strategy may be that articulated by Klaus Illum for the Danish Technology Board, the official adviser of the Danish parliament on science and technology matters, and the Danish Society of Engineers.²⁶⁵ Illum argued for a two-part strategy: (i) figure out when the peak in world oil production might be; and (ii) ensure that oil consumption is falling when large price increases happen. Then painless accommodation to the high prices will be a matter ‘only’ of ensuring an appropriate rate of reduction in use, rather than instigating the much more difficult transition from rising to falling consumption.²⁶⁶

There is an alternative strategy, perhaps one more consistent with the view that there will not be a peak in oil production. It is to do nothing except wait for the market to sort things out. High oil prices will force necessary remedial action involving reduced use or raised supply, or both, thereby bridging the gap between production and consumption.²⁶⁷

Two lines of evidence suggest that such a market response will be very slow. The first concerns the low price elasticities of transport activity discussed in Section 5.4. Transport activity varies little with oil price, at least in the short term. Therefore the impacts of price increases are felt strongly in that they raise shares of household and business income going towards transport. The second line of evidence concerns industry rates of investment in oil exploration. They have been at low levels for many years, notwithstanding high oil prices, because of “the falling success rate for exploration”. Profits have instead been spent on buying other companies and on investments in enhancing recovery rates from existing wells.²⁶⁸ Thus, even higher prices will not necessarily result in more production that moderates the prices.

The consequence of unprepared-for high prices for transport fuel would be high transport prices for households, locked into increasingly prohibitive transport costs because of the need to travel—a result of land-use patterns—and lack of alternative means to do so. Even more serious could be the already-noted constraints on business activity.

Thus, a more prudent approach is to plan for high prices by reducing consumption in advance of them. This approach is being increasingly advocated, particularly in the U.S.²⁶⁹

Because of its high share of total oil use and even higher share of growth in use, transport should be the focus of action to reduce Canada's oil consumption. There are basically three things that can be done: (i) reduce the amount of transport activity; (ii) improve the efficiency with which oil is used for transport; and (iii) use fuels for transport other than oil.

In strategizing about how to accommodate oil constraints in these ways, and reduce GHG emissions, the priority of objectives might reasonably be this: (i) preventing further growth in oil use for trucking; (ii) reducing oil use for other transport purposes, notably the movement of people; and (iii) reducing oil use for trucking.

Although most people think about the movement of people when considering how to reduce transport activity and transport's impacts, priority here is proposed for the movement of freight, particularly *prevention of further increases* in oil use of the kind illustrated in Box 6. It is these increases that have mostly driven Canada's *growth* in oil use since 1990.

Second priority is given to *reducing* oil use for the movement of people. This use is the largest single factor in Canada's oil use. Thus, a particular level of reductions in oil use would have the largest overall effect if achieved for this type of transport activity. Moreover, to the extent that fuel use for the movement of people is more discretionary than fuel use for freight movement, there is considerable scope for achieving such reductions, particularly for what is generally regarded as 'leisure' travel.

The lowest but still important priority is given to *reducing* oil use for freight transport. This is separated from the first priority of preventing further increases for this purpose partly to highlight the magnitude of the task with respect to freight transport and partly because it may be reasonable to approach the freight transport challenge in the two indicated stages.

Transport is more complex than to allow a simple division into the movement of people and the movement of freight. For example, where cars are used for business purposes, particularly to carry samples or other business-related material, their use is more akin to the movement of goods. It would be hard to move much of this activity to public transit. More complex is the role of shopping trips in the supply chain. Current trends towards consolidation of retail outlets, particularly at the edge of urban areas, mean that the final step from field to table or from factory to home is increasingly performed by the consumer, with considerable expenditure of energy. One analysis suggested that 80 per cent

of the transport energy in moving breakfast cereal from field to table is typically expended in the shopping trip. The other 20 per cent is expended in movement of the farm products to storage and then to the manufacturers, and the finished products to wholesalers and retailers.²⁷⁰

6.2. Canadian challenges and opportunities

The Canadian situation is sufficiently distinctive that temptations simply to borrow solutions from other places should be resisted.

Canada's distinctive oil predicament was set out in Chapter 3. Although a net exporter of oil, Canada is already importing almost as much of its oil consumption as the U.S. (59 vs. 66 per cent in 2003). In the U.S., the high share of imports is increasing concern, but the matter hardly receives a mention in Canada. With China's interest in purchasing Canadian oil,²⁷¹ and continuing obligations under NAFTA to supply the U.S., imports as a share of Canadian use could rise much higher. Oil-producing parts of the country would be able to more than offset higher costs of oil use, while other parts could experience serious adverse effects, with resulting major strains on the national fabric.

Another distinctive feature of Canada's energy situation is the relative bounty of opportunities for electricity generation, including generation from renewables.²⁷² Moreover, Canadians have control over this generation and how it is used to a much greater degree than over other resource use.²⁷³ Canadians might thus seem to be in an especially favourable position to accelerate moving transport energy use towards electric drives.

Canada's strong dependence on trade at first sight seems to be a disadvantage as the cost of transport rises. The dependence is indeed a disadvantage as long as it contributes to transport's having a higher-than-usual share of the economy. However, heavy dependence on trade also presents an advantage. As transport prices rise, opportunities to localize production will become more attractive. An economy with a lower share of trade would not have as many opportunities to avoid rising energy prices in this way.

Some localization of production could be more energy-intensive than the transport it replaces—e.g., food production in greenhouses—and thus would not be a productive response to energy constraints. This is one area where the market could well sort out what would be of value. However, research on the advantages of localization of production would be of value to help break path dependence in production systems that maintained 'transport-heavy' practices even though alternatives might be available.

Yet another relevant feature of the Canadian situation, touched on in 0, is the higher settlement density of many of its urban regions, at least in relation to the U.S. These higher densities make expansion of urban transit systems and other transport innovations a more feasible proposition.

6.3. Elaborating energy and transport scenarios as a tool for strategy development

A scenario study is a useful way of exploring options for the future of a sector such as transport. It is essentially a disciplined use of imagination about potential futures that allows exploration of relevant factors, risks, and opportunities. Royal Dutch Shell pioneered scenario planning techniques in the late 1960s and used them to attain superior performance following the 1973 oil shock. The Royal Dutch/Shell Group of Companies²⁷⁴ and national governments—e.g., Norway and Singapore²⁷⁵—have relied upon scenario-based assessments to inform their industrial and natural resource development strategies. Several agencies, including the OECD²⁷⁶ and Israel’s Transportation Research Institute,²⁷⁷ have used scenario studies to help plan sustainable transport systems. In Canada, scenario-based assessment techniques have been used to create economic development strategies for Ontario’s financial and information technology sectors.²⁷⁸ However, this fruitful approach has not been used to assess the prospects for transport, a key enabler of Canada’s economic and social progress. Moreover, the last Canada-wide investigation of transport options was published more than 12 years ago and focused exclusively on intercity passenger travel.²⁷⁹

A scenario study would be a useful tool for development and analysis of Canada’s transport options in relation to possible energy futures, all to inform appropriate policy development at federal, provincial, and local levels. For illustrative purposes only, here are examples of the *kinds of* scenario set that might be explored in such a study:

1. Transport fuel prices do not increase substantially; ICEs, including jet engines, remain dominant transport technologies.

This may be the least realistic of the four scenario possibilities presented here. It is a ‘business-as-usual’ scenario, made possible by the assumption that present or similar transport fuels will be available throughout the scenario period, i.e., until 2030, at present or lower prices. Even though potentially unrealistic, it is developed to provide a baseline of transport and impacts activity until 2030 against which to compare the activity under other scenarios.

2. Transport fuels become much more expensive; but ICEs continue to prevail.

This scenario is similar to the first except that fuel prices are much higher. There is little change in the appearance of transport, but use declines, perhaps dramatically, with consequences for Canada’s economic and social fabric. There is an implied assumption that fuel prices, while high, are not sufficient to force changes in technology, or that changes cannot be realized.

3. Hydrogen-fuelled fuel cells prevail.

Here, the basic transport technology changes dramatically, at least for surface vehicles. The scenario speaks to realization by 2030 of what presently seems to be the vision of most of the automobile industry and several governments: widespread use of fuel-cell-powered, independently mobile electric vehicles, together with supporting infrastructure for delivery of hydrogen to vehicles. Aviation might continue to be based on jet engines, perhaps using other fuels than hydrogen.

4. Tethered vehicle systems prevail.

Again, there is a dramatic change in basic transport technology, at least for surface

vehicles. This scenario supposes that oil constraints are sufficient to force a change in technology, but that a hydrogen-fuel-cell-based transport system is found to be not feasible or too energy intensive. A further difference from the first scenario is that the scope for deployment of independently mobile vehicles is much more limited, requiring substantial changes in how people and freight are moved, with consequent economic and social changes. In terms of the behavioural changes required, this scenario could have more in common with the second scenario than with the third.

There are many other options for fruitful scenario development. For example, rather than conceive scenarios in terms of availability of fuel and transport technology, scenarios could be differentiated in terms of predefined amounts of transport activity, or in terms of degree of contribution to overall sustainability. The key features of a useful scenario set are (i) that it provides distinctive alternatives for analysis, comparison, and the drawing of conclusions, and (ii) that the selected alternatives bracket the reasonable range of possible futures.

We believe that medium-term planning for Canada's energy and transport future is urgently required, and a well-executed scenario study would be a necessary first step towards timely development of effective policy. The study should have a reasonable planning period, say until about 2031, and address all transport in Canada—land, water, and air—together with related energy factors.

Such a medium-term planning exercise and subsequent resulting action requires at least the commitment and resources presently applied to meeting Canada's obligations under the Kyoto Protocol. Indeed, a commitment to achieve dramatic reductions in oil use for transport, to avoid high fuel costs, could well be moved ahead of the present commitment to reduce GHGs. The Kyoto obligation would be met as a consequential feature of such reductions.

This approach would be consistent with the recent request by the federal government to the National Round Table on the Environment and the Economy "to provide and advice and recommendations on the development of a long-term energy and climate change strategy for Canada". The text of the request to NRTEE, as reproduced at NRTEE's Web site,²⁸⁰ mostly concerns the climate change aspects of the request, and these must be given the needed attention. However, Canada's climate change predicament arises mostly on account of our energy use, and our energy predicament could well be more immediate. Moreover, the need to reduce oil consumption can be articulated more clearly than the need to prevent climate change. Accordingly, there could be more public support for a campaign that focuses on reducing oil use for transport, both to avoid high prices and to reduce climate impacts, than for a campaign that focuses on climate impacts alone.

Thus, a strategy for responding to the federal government's request could well involve a focus on Canada's energy future—particularly oil, and particularly oil used for transport—ensuring at each point that what is proposed is consistent with the need to reduce the extent of anticipated climate change.

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The Canadian Transport Futures Assessment (CTFA) is a five-year research program that proposes to investigate alternatives for Canada's transport over the period until 2031, and through this analysis to advance fundamental knowledge about how policies are formulated and implemented in the public and private sectors.

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The authors are entirely responsible for the contents of the report and the selection of sources to illustrate points made. The views expressed here do not necessarily represent views held by our colleagues or by the NRTEE.

End notes

- 1 The recent *Millennium Ecosystem Assessment*, available at the URL below (pre-publication final draft), highlights the role of the by-products of fossil fuel combustion as a factor in ecosystem degradation.
1. <http://www.millenniumassessment.org/en/Products.aspx>. Accessed June 3, 2005.
- 2 In February 2005, the president of France, Jacques Chirac, called for developed countries to cut GHG emissions by 75% from current levels by 2050. (See the Reuters report at the first URL below.) European Union environment ministers adopted such a position in early March, proposing targets of 15-30% reductions for 2020 and 60-80% reductions for 2050. Later in March, EU heads of state and government endorsed only the target for 2020, and then only as a goal to be considered “in the light of future work on how the objective can be achieved, including the cost-benefit aspect”. (see the second URL below.)
1. <http://www.planetark.com/dailynewsstory.cfm/newsid/29542/story.htm>. Accessed June 3, 2005.
2. <http://www.euractiv.com/Article?tcaturi=tcm:29-137205-16&type=News>. Accessed June 3, 2005.
- 3 The failure of production to keep up with demand is discussed in detail later in this report. A taste of what is to come can be gained from an Associated Press report dated March 12, 2005. The energy minister of Algeria, a member of the Organization of Oil Exporting Countries (OPEC), was quoted as saying that “OPEC has reached its production limits. It doesn’t have much production capacity.” This assertion challenges the conclusion of the International Energy Agency on Page 32 of its *World Energy Outlook 2004* that “OPEC countries, mainly in the Middle East, will meet most of the increase in global demand”.
- 4 Data on trade in goods as a share of GDP is among the World Bank’s *World Development Indicators 2004*, available online at the URL below.
1. <http://www.worldbank.org/data/dataquery.html>. Accessed June 3, 2005.
- 5 The data in Box 1 are from Kenworthy J, Laube F, *The Millennium Cities Database for Sustainable Transport*, Union Internationale des transports publics (UITP), Brussels, Belgium, 2001 (CD-ROM). This resource is available for a fee from UITP at the URL below.
1. <http://www.uitp.com>. Accessed June 3, 2005.
- 6 The other net oil producer is the UK, which, according to the *BP Statistical Review of World Energy*, available at the URL below, reached a peak oil production of 136.8 million tonnes in 1999 but achieved production of only 105.6 million tonnes in 2003. Canada’s total production in these two years was 121.0 and 141.9 million tonnes.
1. <http://www.bp.com/subsection.do?categoryId=95&contentId=2006480>. Accessed June 3, 2005.
- 7 See Adams J, *The Social Implications of Hypermobility*. Paper presented at an OECD workshop held in Ottawa, Ontario, in October 1998 and entitled ‘The Economic and Social Implications of Sustainable Transportation’. The paper is appended to the workshop proceedings, which are available at the URL below.
1. [http://www.oilis.oecd.org/oilis/1999doc.nsf/63c71d2d4054d0f6dc125685d0053aee4/c125685b002f5004c125686b005cb510/\\$FILE/00071363.PDF](http://www.oilis.oecd.org/oilis/1999doc.nsf/63c71d2d4054d0f6dc125685d0053aee4/c125685b002f5004c125686b005cb510/$FILE/00071363.PDF). Accessed June 3, 2005.
- 8 Information in this paragraph is from a two-part series by Carl Sulzberger in *IEEE Power and Energy Magazine*, 2004, entitled ‘An early road warrior: electric vehicles in the early years of the automobile’ (May/June issue, pp. 66-71) and ‘Early road warrior, Part 2: Competing electric and gasoline vehicles’ (September/October issue, pp. 83-88). The 4,192 automobiles produced in the United States in 1900 more than doubled the number on the

road (*Facts and figures of the Automobile Industry*. New York: National Automobile Chamber of Commerce, 1932).

⁹ The amount indicated in the first source in Note 8 was \$1 million. According to the source at the URL below, a dollar in 1905, when much of this work was ongoing, was worth about 22 of the dollars used in 2005.

1. <http://minneapolisfed.org/Research/data/us/calc/hist1800.cfm>. Accessed June 3, 2005.

¹⁰ See the first two sources detailed in Note 8.

¹¹ See Table 2 in Chan CC, Wong YS, Electric vehicles charge forward. *IEEE Power & Energy Magazine*, 25-33, November/December 2004.

¹² See the table on Page 443 of *World Energy Outlook 2004*. Paris, France: International Energy Agency, 2004.

¹³ ICEs include Otto-cycle (spark ignition) and diesel (compression ignition) engines as well as gas turbines (jet engines).

¹⁴ See the table on Page 443 of the source detailed in Note 12.

¹⁵ Box 2 is based on data on new vehicles sales in Table 2 of *Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2004*, U.S. Environmental Protection Agency, Washington DC, 2004, available at the first URL below. (The values in the left-hand panel are metric conversions of so-called ‘adjusted 55/45’ values.) Less detailed data are available about vehicles sold in Canada, which generally conform to the same fuel consumption standards but tend to have lower average consumption because of a different fleet mix. The only readily available comparable source on Canadian vehicles is Schingh M, Brunet É, Gosselin P, *Canadian New Light-Duty Vehicles: Trends in fuel consumption and characteristics (1988-1998)*. Natural Resources Canada, Ottawa, 2000, available at the second URL below. Comparing data for the 1998 model year, the latest year covered by both reports, the Canadian automobile fleet used on average slightly less fuel than the U.S. fleet (9.2 vs. 9.6 L/100 km, in the terms of Box 2) as did the light truck fleet (13.1 vs 13.4 L/100 km). For that model year, 45% of light-duty vehicles sold in the U.S. were light trucks, compared with 43% in Canada. Comparison of the more recent data in Box 2 with those in the source detailed in Note 40 suggests that the gaps between the Canadian and U.S. fleets have widened since 1998.

Note that the category of light-duty vehicles includes all vehicles weighing less than 3,856 kilograms (8,500 pounds). The vast majority of these vehicles are used for personal transport, but a very few cars and (in Canada in 2001) about a quarter of light trucks are purchased for commercial purposes. Some further information about fuel use by Canadian light-duty vehicles is in a presentation by Peter Reilly-Roe of Natural Resources Canada at a conference held in Toronto by Pollution Probe in April 2003, available at the third URL below. The rated fuel uses in Box 2 and noted elsewhere in this paper do not necessarily indicate actual performance under everyday conditions. A recent analysis by the European Conference of Ministers of Transport (ECMT) and the International Energy Agency (IEA) noted that among OECD countries Canada—i.e., Natural Resources Canada—has provided the only recent basis for assessment of what it describes as the ‘shortfall’ between rated fuel economy and actual fuel economy, characterized in this way: “Their data showed that actual fuel consumption was 23.1% higher than the “55/45” combined city/highway fuel consumption measured on the test for cars, and 27.9% higher for light trucks. Small cars showed a

higher level of shortfall (25.3%) than large cars (22.5%). In addition, vehicles in urban areas had a shortfall of 26.4% compared to vehicles in rural areas with a shortfall of 17.4%.” The analysis noted “concerns that national fuel consumption reduction goals based on test values will not be met in reality and that consumers will lose faith in reported fuel economy figures”. The quotations are from Pages 28 and 9 of *Making Cars More Fuel-Efficient*, ECMT and IEA, Paris, May 2005. This document is available for a fee at the fourth URL below.

1. <http://www.epa.gov/otaq/cert/mpg/fetrends/420r04001.pdf>. Accessed June 3, 2005.
2. <http://oee.nrcan.gc.ca/english/programs/pdfs/Doc5e.pdf>. Accessed June 3, 2005.
3. <http://www.pollutionprobe.org/Happening/pdfs/transportconf/reillyroe.pdf>. Accessed June 3, 2005.
4. <http://www1.oecd.org/cem/events/JustPub/justCars.htm>, Accessed June 4, 2005.

¹⁶ The cited fleet averages are figures given on Page 10 of *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America’s Energy Challenges*. Washington DC: National Commission on Energy Policy, December 2004, available at the first URL below.

1. <http://www.energycommission.org/ewebeditpro/items/O82F4682.pdf>. Accessed June 3, 2005.

¹⁷ Box 3 is based on the same source as Box 2 (see Note 15).

¹⁸ This calculation assumes that 10% changes in weight and power produce respectively 6% and 3% changes in fuel consumption, other things being equal. (See Van den Brink RMM, Van Wee B, Why has car-fleet specific fuel consumption not shown any decrease since 1990? Quantitative analysis of Dutch passenger car-fleet specific fuel consumption. *Transportation Research Part D*, 6, 75-93, 2001.) As Van den Brink and Van Wee note, similar increases in vehicle weight and power have occurred in Europe. (Note that previous versions of this estimate—i.e., in earlier drafts of this paper—assumed that 10% changes in weight and power both produce 10% changes in fuel consumption.)

¹⁹ More specifically, the U.S. is the only country that requires that new vehicles meet fuel use standards, know as Corporate Average Fuel Economy (CAFE) standards. A voluntary agreement exists in Canada in respect of Company Average Fuel Consumption (CAFC) standards that essentially mirror the CAFE standards (see the URL below). The CAFE standards allow a manufacturer’s fleet of light trucks to use more fuel on average than a fleet of regular cars.

1. http://www.tc.gc.ca/securiteroutiere/asfbb/FCpdm/en/cafc/page1_e.htm. Accessed June 3, 2005.

²⁰ A slight increase in fuel use has resulted from the increase in light trucks’ share of new vehicles. This is apparent in the left-hand panel of Box 2.

²¹ Box 4 is based on the same source as Box 2 and Box 3 (see Note 15).

²² Data in this paragraph are from the Annual Reports on Statistics Canada’s *Canadian Vehicle Survey*, 2000 and 2003, Catalog No. 533-233-XIE.

²³ According to the *Canadian Vehicle Survey* (Statistics Canada, *CANSIM II*, Table 4050044), 51% of light-duty vehicles (less than 4.5 tonnes) on the road in the fourth quarter of 2003 were seven years old or less and 76% were 12 years old or less.

²⁴ A proposal for such an incentive scheme was set out in *Background Paper for a Post-Kyoto Transport Strategy* prepared for the four workshops held by The Centre for Sustainable Transportation in 2001-2002, as follows: “The kind of program in mind is one in which a \$1,000 per litre/100 km improvement is rebated for each vehicle replacement or retirement, together with a \$200 per litre/100 km annual tax on each vehicle in use. Such a program

would require regular certification of the fuel efficiencies of all vehicles on the road. It may be simpler to provide the rebates but raise fuel taxes to even higher levels than is proposed here.” The *Background Paper* is available at the URL below.

1. <http://www.csctcd.org/CSTadobefiles/Background%20paper%207.pdf>. Accessed June 3, 2005.

- 25 This estimate is based on data in Van Wee B, Moll HC, Dirks J, Environmental impact of scrapping old cars. *Transportation Research Part D*, 5, 2000, pp. 137-143, and in Das S, et al, Automobile recycling in the United States: energy impacts and waste generation. *Resources, Conservation and Recycling*, 14, pp. 265-284, 1995.
- 26 There are no good trend data on the age of vehicles on the road in Canada. In the U.S., the median age of automobiles on the road increased from 4.9 years in 1970 to 8.3 years in 2000; for trucks, the corresponding increase was from 5.9 to 6.9 years (see Table 1-25, Page 40, in *National Transportation Statistics*, Bureau of Transportation Statistics, U.S. Department of Transport, 2002, available at the first URL below). Data on the “durability of new vehicles” in Canada are provided Stanczak M, *The Future of Technology in the Aftermarket*, Automotive Industries of Canada (undated), available at the second URL below. The data suggest that 1970s automobiles lasted for 150,000-160,000 kilometres, on average, whereas automobiles produced in the 1990s lasted for 220,000-250,000 km, and those produced in 2000 and later will last over 300,000 km. As durability has increased, the share of new vehicles on Canadian roads has been declining, from about 11% in the 1960s to about 8% in the 1990s. This information is based on several Statistics Canada sources: CANSIM II Table 790001 (New Motor Vehicle Sales, Canada, Provinces and Territories); *Historical Statistics of Canada*, Table T147 (vehicle fleet data for 1946-1975); CANSIM I Label D462103 (vehicle fleet data for 1975-1998); and CANSIM II Table 4050004, Series V1456734 (vehicle fleet data for 1999-2002).
1. http://www.bts.gov/publications/national_transportation_statistics/. Accessed June 2, 2003.
2. http://www.aiacanada.com/downloads/article6_e.pdf. Accessed June 2, 2003.
- 27 This assumes essentially full replacement by 2020 of the fleet of personal vehicles presently on the road, and use of incentives and disincentives that together encouraged purchase of fuel-efficient vehicles (see Note 24).
- 28 According to one source, 52% of new cars sold in Europe in 2004 had diesel engines (see the first URL below). Diesel engines use about 35% less fuel than equivalent gasoline engines. For example, the U.S.-rated performance of Volkswagen’s manual five-speed 2005 Golf automobile is 5.5 litres per 100 kilometres; that of the gasoline version is 8.8 L/100 km. (See the second URL below.) Some of this greater efficiency arises because diesel fuel is more ‘energy dense’ than gasoline; it takes a little more crude oil to make a litre of diesel fuel than a litre of gasoline. However, even if a switch to diesel fuel were to result in savings in crude oil use of ‘only’ 20%, this would be more than enough to offset Canada’s anticipated population growth of 16% by 2020, which may also be the anticipated growth in the number of vehicles on the road. In refining, production of diesel and gasoline are not completely inter-substitutable. The high share of diesel use in Europe has led to a surplus of gasoline, much of which is exported to eastern Canada. The regularly marketed automobile—only in Germany—that has the lowest fuel use is Volkswagen’s Lupo 3L. It has a conventional diesel engine rather than a hybrid. Its only unusual fuel-saving feature is cessation of engine operation whenever the vehicle is stationary for more than a few seconds, and instant restart when the ‘gas’ pedal is depressed. The Lupo 3L is described in Box 10 and Note 59.

1. http://www.mwerks.com/artman/publish/industry_news/printer_659.shtml. Accessed June 3, 2005.
 2. <http://www.fueleconomy.gov/feg/FEG2005.pdf>. Accessed June 3, 2005.
- 29 The *Memorandum of Understanding between the Government of Canada and the Canadian Automotive Industry Respecting Automobile Greenhouse Gas Emissions*, dated April 5, 2005, is at the URL below.
1. http://www.nrcan-rncan.gc.ca/media/mous/2005/20050405_e.htm. Accessed June 3, 2005.
- 30 The reference case for 2010, as agreed by the parties to the MOU, is based on the 2010 forecast in Appendix C of *Canada's Emissions Outlook: An Update, December 1999*, available at the URL below.
1. <http://www.nrcan.gc.ca/es/ceo/outlookc.pdf>. Accessed June 3, 2005.
- 31 *Outlook* refers to Appendix C of *Canada's Emissions Outlook: An Update, December 1999*, detailed in Note 30. The estimates and projections for 1990-2010 are in Table C-26, specifically in the categories gasoline-fuelled automobiles and gasoline-fuelled light-duty trucks. These projections for 2010 were respectively 53.0 megatonnes of carbon dioxide equivalent, and 37.5 Mt., hence the 'reference case' for 2010 in the MOU. (In the MOU, the total is represented as 90.51 Mt, although in the indicated document the relevant figures are given to one decimal place only.)
- 32 *Database* refers to Natural Resource Canada's *Comprehensive Energy Use Database*, available at the first URL below. The estimates for 1990-2002 are in the table entitled 'Secondary energy use by transportation mode', specifically in the categories small cars, large, cars, passenger light trucks, and freight light trucks. The Centre has more often used this rather than the next source (*Inventory*, see Note 33) because of the convenience of the presentation and the strong link with energy considerations. The discrepancies between the two sets of emissions estimates are reconciled in Appendices A and B of *Energy Use Data Handbook*, Natural Resources Canada, June 2004, available at the URL below.
1. http://www.oee.nrcan.gc.ca/corporate/statistics/neud/dpa/comprehensive_tables/index.cfm?attr=0. Accessed June 3, 2005.
 2. http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/data_e/Handbook04/Datahandbook2004.pdf. Accessed June 3, 2005.
- 33 *Inventory* refers to *Canada's Greenhouse Gas Inventory, 1990-2002*, Environment Canada, Ottawa, August 2004, available at the URL below. The estimates for 1990-2002 are in the table on Page 206, specifically in the categories gasoline-fuelled automobiles and gasoline-fuelled light-duty trucks.
1. http://www.ec.gc.ca/pdb/ghg/1990_02_report/1990_02_report_e.pdf. Accessed June 3, 2005.
- 34 The projections for 2005 and 2010 were performed by applying Microsoft Excel's FORECAST function to the relevant 1990-2002 estimates. This function predicts new values based on a least-squares linear regression of a range of known values.
- 35 A recent report suggests that the increase in Canada's GHG emissions from 2002 to 2003 may be unusually steep. (See Calamai P, Greenhouse gases growing faster than economy. *Toronto Star*, May 30, 2005.)
- 36 This is a necessary assumption because the auto industry has essentially no other tool to influence the performance of vehicles on the road.

- 37 This estimate of the share of new vehicles in the total fleet of light-duty vehicles is based on data in the first source detailed in Note 32. Actual values from 1990-2002 were extrapolated to 2006-2010 in the manner detailed in Note 34. The estimated total for these years is 48.9%, rounded in the text to 50%.
- 38 According to the table on Page 32 of the annual report for 2003 on the *Canadian Vehicle Survey* (Statistics Canada, Catalogue No. 53-223-XIE, June 2004, available at the first URL below), vehicles aged six years or less were responsible for 53.4% of kilometres performed in 2003 by all light-duty vehicles. Thus, vehicles five years old or less may have been responsible only about 45% of kilometres performed, which, according to the source detailed in Note 32 was about their share of the total fleet. Thus, the reduction required of new vehicles from 2005-2010 will be about twice that of all vehicles, because about 50% of the light-duty fleet will be replaced.
It may be noted in passing that U.S. odometer data suggest that newer vehicles are driven substantially more than older vehicles (Table 8.13 of Davis SC, Diegel SW, *Transportation Energy Data Book: Edition 24*, Oak Ridge National Laboratory, Oak Ridge, Tennessee, December 2004, available at the second URL below). However, per-capita vehicle ownership in the U.S. is much higher, many more households in the U.S. have more than one vehicle, and thus more differentiation in usage between newer and older vehicles might be expected.
1. <http://www.statcan.ca/english/freepub/53-223-XIE/53-223-XIE2003000.pdf>. Accessed June 3, 2005.
2. http://cta.ornl.gov/data/tedb24/Edition24_Full_Doc.pdf. Accessed June 3, 2005.
- 39 Little can be achieved for the 2006 model year, some of whose vehicles are already in production, and little seems possible for the 2007 model year, tooling for which may well already be arranged. Accordingly, the reduction will be phased in such that if $x\%$ is the annual reduction required by 2010, the reductions in successive model years from 2006 to 2010 will be 0, 0.5x, 1.0x, 1.5x, 2.0x. For the table in Box 5, the calculated reduction for 2010 (i.e., twice the average reduction required of new vehicles, or four times the reduction required of all vehicles) has been rounded to the nearest five percentage points.
- 40 See Page 24 of *State of Energy Efficiency in Canada 2005*, Natural Resources Canada, Ottawa, 2005, available at the URL below.
1. http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/data_e/see05/SEE05.pdf. Accessed June 3, 2005.
- 41 See Page 24 of the source detailed in Note 40. There the middle chart represents average fuel use by model 2003 personal vehicles as being between nine and ten litres per 100 kilometres, in a trend of generally declining fuel consumption.
- 42 These are data on the U.S. fleet of light-duty vehicles, from Table 2 of *Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2004*, U.S. Environmental Protection Agency, Washington DC, 2004, available at the URL below. Canadian data for the period are not readily available, but are likely similar.
1. <http://www.epa.gov/otaq/cert/mpg/fetrends/420r04001.pdf>. Accessed June 3, 2005.
- 43 Data on the rated performance of 2005 vehicles are from *Fuel Consumption Guide 2005*, Natural Resources Canada, 2005, available at the URL below. Whether the values in this *Guide* correspond to the values in the document detailed in Note 40 needs verification. On the face of it, the *Guide* values seem too high to result in the sales-weighted averages represented in the referenced figure in the *State of Energy Efficiency in Canada 2005*.
1. <http://www.oee.nrcan.gc.ca/transportation/tools/fuel-consumption-guide/pdf/fuel-consumption-guide-2005.pdf>. Accessed June 3, 2005.

- 44 The increase in travel with improvements in fuel efficiency is often termed the ‘rebound’ effect, and also the Jevons effect after the 19th-century British mathematician and political scientist William Stanley Jevons, who noted that improvements in the efficiency with which coal was used did not necessary lead to the use of less coal.
- 45 The relevant words in the MOU are, “the MOU does not constitute or establish a legally binding agreement”; i.e., there is no penalty for non-compliance, although the MOU does note that “the Government of Canada has the right to regulate any and all subjects within the government’s purview, and will do so if it deems necessary”. (The MOU is detailed in Note 29.)
- 46 According to the report *Encouraging Environmentally Sustainable Growth In Canada*. Organization for Economic Cooperation and Development, Paris, France, 2001 (Economics Department working Paper No. 290), available at the URL below, “The frequent recourse to voluntary agreements has not proved effective in dealing with toxic substances or greenhouse gas emissions”.
1. <http://www.oecd.org/dataoecd/31/26/1891973.pdf>. Accessed June 3, 2005.
- 47 The “Sword of Damocles” reference was in a statement by Adrian Coleman, spokesperson for the Association of International Automobile Manufacturers of Canada, reported in *Collier R, Canada, carmakers sign tough emissions pact: Deal could force adoption of similar stringent rules for vehicles sold in U.S. San Francisco Chronicle*, April 6, 2005. (Damocles was an ancient court sycophant who observed that riches and power bring constant danger.)
- 48 The data in this paragraph are from *Energy Use Data Handbook*. Ottawa: Ontario: Natural Resources Canada, June 2004. The data in the *Handbook* are available at the URL below. (Note that this source is essentially the same as the first source detailed in Note 32.)
1. http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/handbook_tables.cfm?attr=0. Accessed June 3, 2005.
- 49 The reduced fuel use per tonne-kilometre of freight carried is reported on Page 24 of the document detailed in Note 40. The same reduction (24.7%) can also be derived from source detailed in Note 48. There, the components of the reduction can also be assessed.
- 50 This estimate is also based on the source detailed in Note 48. According to this source, load factors of medium-duty vehicles did not change across the period 1990-2002.
- 51 Data are not available on the weights of trucks on Canadian roads. U.S. data are available, and likely show the same trends as Canadian data. Table 1-21 of *National Transportation Statistics 2004*, Bureau of Transportation Statistics, Washington DC, at the URL below, suggests that the unladen weights of medium- and heavy-duty trucks fell respectively by 19% and 12% across the period 1992-2002.
1. http://www.bts.gov/publications/national_transportation_statistics/2004/index.html. Accessed June 3, 2005.
- 52 The statement about truck loading is based on analysis in The Centre for Sustainable Transportation’s *Sustainable Transportation Monitor*, No. 10, June 2004, available at the first URL below. The analysis was based on results of the 1999 *National Roadside Study*, a link to which is at the second URL below.
1. <http://www.cstctd.org/CSTadobefiles/STM10E-final.pdf>. Accessed June 3, 2005.
2. <http://www.ccmta.ca/english/publicationandreports/publicationandreports.html>. Accessed June 3, 2005.
- 53 The analysis supporting the statement about load factors is in the first source detailed in Note 52.

- 54 Box 7 is from McKinnon A, *Oil saving opportunities in freight transport*. Paper presented at the IEA workshop detailed in Note 155. The paper is available at the URL below.
1. http://www.iea.org/textbase/work/2005/oil_demand/Oiltransportwkshp/pdf/iea-day2/mckinnon.pdf. Accessed June 3, 2005.
- 55 Box 8 is taken from the source detailed in Note 54.
- 56 Evidence that intermodal freight transport might require use of *more* energy than unimodal transport seems to have been laid to rest by Kreutzberger E, Macharis C, Vereecken L, Woxenius J, *Is intermodal freight transport more environmentally friendly than all-road freight transport? A review*. Paper presented the NECTAR conference No. 7, Umeå, Sweden, June 2003.
1. http://www.mot.chalmers.se/staff/johwox/_private/English/Articles/2003%20NECTAR%20Ume%C3%A5%20Kr%20Ma%20Ve%20Wo.pdf. Accessed June 3, 2005.
- 57 See Erickson Jr TF, Urban freight economics: A new rail paradigm for large lots. *Transportation Journal*, 40, 5-15, 2001.
- 58 Box 9 is based on data in Table 4.25 of *Transportation Energy Data Book 24*, Oak Ridge National Laboratory, U.S.A., 2000, available at the URL below.
1. http://cta.ornl.gov/data/tedb24/Edition24_Full_Doc.pdf. Accessed May 18, 2005.
- 59 Box 10 is based on manufacturers' information (Lupo 3L), on vehicle data in Natural Resource Canada's Fuel consumption Guide 2005, detailed in Note 43, and on summary data (for 2003) in the document detailed in Note 40. Note that the Prius performs better in urban driving than on highways, and the Insight does not. This appears to be because the Prius has a relatively larger battery system that takes the vehicle to a higher speed before the ICE starts up.
- 60 The Lupo 3L and the technically similar Audi A2 3L are the most fuel-efficient cars in regular production, available only in Europe. '3L' in each case means a rated overall fuel use of 3L/100 km. Early in 2005, their manufacturer, Volkswagen, discontinued development of a '1L' automobile, with a rated fuel use of 1L/100 km (i.e., 283 miles per imperial gallon). The prototype had two seats, one in front of the other, with no place for luggage. All three cars have or had diesel engines that stopped when the vehicle was stationary. In comparing fuel use by diesel- and gasoline-fuelled vehicles, the greater energy density of diesel fuel should be noted (about 41 vs. 35 megajoules/litre). Thus, although the Lupo 3L requires less fuel to travel 100 kilometres (3.1 vs. 3.6 L, see Box 10) it requires more energy to achieve the same distance (127 vs. 126 megajoules).
- 61 FedEx began using hybrid ICE-electric trucks for deliveries in Sacramento, California, in April 2004. See the URL below.
1. <http://www.evworld.com/view.cfm?section=communique&newsid=5340>. Accessed June 3, 2005.
- 62 The largest investment in hybrid electric-ICE buses, bought to replace dual-mode trolley-ICE buses, does not seem to be delivering the promised fuel efficiency. See Hadley J, Hybrid buses' fuel economy promises don't materialize. *Seattle Post Intelligencier*, December 13, 2004, at the URL below.
1. http://seattlepi.nwsource.com/transportation/203509_metro13.html. Accessed June 3, 2005.
- 63 The Canadian firm RailPower is a leader in hybrid locomotive technology. See the URL below.
1. http://www.railpower.com/dl/news/news_2005_03_14a.pdf. Accessed June 3, 2005.

- ⁶⁴ For information about plug-in hybrids, see the first URL below. Also see the Web site of the California Cars Initiative at the second URL below.
 1. <http://www.iags.org/pih.htm>. Accessed June 4, 2005.
 2. <http://www.calcars.org/>. Accessed June 4, 2005.
- ⁶⁵ Production of each Prius is said to have initially required a subsidy by Toyota of up to \$30,000. A recent report suggests that hybrids in the U.S. are priced at US\$3,000 more than comparable regular cars, and cost US\$7,000 more to manufacture. (See Kim C-R, Automakers bank on green. *National Post*, January 21, 2005, available at the second URL below.) According to the guide at the first URL below, the base price for the Prius in the U.S. is close to \$21,000; that for the other Toyota vehicle classified as mid-sized, the ICE-powered Camry, rated at 8.3 L/100 km vs. the Prius at 4.2 L/100km, is close to \$18,000. There are reports that near-new Priuses are selling at as much as \$5,000 above the sticker price to people who do not want to sit out the three-month waiting list. (See the second URL below.)
 1. <http://www.autobuyguide.com/>. Accessed June 4, 2005.
 2. http://money.cnn.com/2005/04/11/Autos/used_prius/, Accessed June 4, 2005.
- ⁶⁶ An indication of industry commitment and government support is a recent announcement that General Motors and DaimlerChrysler have signed five-year agreements with the U.S. Department of Energy for the development of fuel-cell vehicles. (Deals to develop fuel cell vehicle. *New York Times*, March 31, 2005). Under the deal, GM and DoE will each spend US\$44 million on manufacturing a total of 40 vehicles (i.e., US\$2.2 million per vehicle). DaimlerChrysler will spend US\$70 million to place fuel-cell vehicles with consumers. Ballard Power Systems Inc. expects to supply more than half of the fuel cells used in this demonstration program (Ballard fuel cells set for U.S. program, *Globe & Mail*, March 31, 2005).
- ⁶⁷ A useful discussion of the challenges faced in developing fuel-cell vehicles, on which some of the discussion here is based, is Ashley S, On the road to fuel-cell cars. *Scientific American*, March 2005.
- ⁶⁸ For challenges concerning use of hydrogen, see the following three papers: (1) Midilli A, Ay M, Dincer I, Rosen MA, On hydrogen and hydrogen energy strategies I: current status and needs. *Renewable and Sustainable Energy Reviews*, 9 255-271, 2005; (2) Midilli A, Ay M, Dincer I, Rosen MA, On hydrogen and hydrogen energy strategies II: future projections affecting global stability and unrest. *Renewable and Sustainable Energy Reviews*, 9 273-287, 2005; and (3) Zhou L, Progress and problems in hydrogen storage methods. *Renewable and Sustainable Energy Reviews*, 9, 395-408, 2005
- ⁶⁹ The official is Bill Reinert, national manager for Toyota's advanced technology group, quoted in the source detailed in Note 67. Nevertheless, Dennis Campbell, president and CEO of Ballard Power systems Inc. vowed in March 2005 that his company will demonstrate a commercially viable fuel cell for vehicles by 2010. (Viable car fuel cell by 2010, Ballard says. *Globe & Mail*, March 30, 2005.) Investors seem to share Mr. Reinert's pessimism. Ballard's share price on the Toronto Stock Exchange fell from \$172 in September 2000 to \$4.32 in mid-May 2005. According to one commentator, investors are exhibiting "a disease called FCF, or Fuel Cell Fatigue. The mantra that 'commercialization is just around the corner' is now a negative" (Mary Lynn Young, Fuel cell fatigue causes research to dry up. *Globe & Mail*, May 27, 2005). Meanwhile, the U.S. Department of Energy announced grants of \$64 million towards 70 hydrogen research and development projects. (See the June 1, 2005, issue of *Energy Efficiency and Renewable Energy News*, U.S. Department of Energy, at the

URL below.)

1. <http://www.eere.energy.gov/news/>. Accessed June 2, 2005.

70 Box 11 is taken from Figure 9 of Bossel U, *Does a Hydrogen Economy make Sense?* Paper to be presented at the European Fuel Cell Forum, Lucerne, Switzerland, July 4-8, 2005, available at the URL below.

1. <http://www.efcf.com/reports/E13.pdf>. Accessed June 4, 2005.

71 For information on the energy cost of charging and discharging, see the URL below.

1. http://www1.electusdistribution.com.au/images_uploaded/battglos.pdf. Accessed June 4, 2005.

72 See Nichol J, *The All-Red Route* (Toronto, Ontario, McArthur and Co., 1999).

73 The data in this row are derived from the electronic version of *Energy Use Data Handbook* detailed in Note 48

74 The data for a hybrid gasoline-electric car are those for the 2004 Toyota Prius midsize car, as posted by the U.S. Department of Energy at the URL below.

1. http://www.fueleconomy.gov/feg/hybrid_sbs.shtml. Accessed June 4, 2005.

75 The data for the ‘very small car’ are those for Volkswagen’s Lupo 3L, a two-seater-plus diesel car available only in Europe and described by the manufacturer as the “first 3L vehicle in production” (see Klaus-Peter Schindler, *The future of the Diesel engine in passenger cars*. Presentation at the 7th Diesel Engine Emissions Reduction Workshop, Portsmouth, Virginia, August 2001, at the first URL below). Manufacturer’s energy-use data are given here, i.e., 2.99 litres/100 km, equivalent to 0.89 mJ/pkm for an occupancy of 1.30 (the present authors’ estimate). In Slide 10 of the cited presentation, a rate of 0.75 mJ/pkm is given for “average rate of occupation” “in urban traffic under 75 km”, which suggests an average occupancy of 1.54 or higher. Testing of the Lupo 3L by Transport Canada indicated highway fuel use of 3L/100 km and city fuel use of 3.8L/100 km (*Advanced Technology Vehicles Program, 2001-2002 Annual Report*, Road Safety and Motor Vehicle Regulation, Transport Canada, January 2003, at the second URL below).

1. <http://www.osti.gov/fcvt/deer2001/schindler.pdf>. Accessed June 4, 2005.

2. <http://www.tc.gc.ca/roadsafety/atvpgm/reports/annual/atvp0102.pdf>. Accessed June 4, 2005.

76 Personal Rapid Transit (PRT) is a generic term for concept systems comprising fully automated small vehicles carrying 1-6 passengers running on guideways at, above or below ground, providing direct origin-to-destination service. A useful review of these and other innovative technologies can be found at a Web site maintained by Jerry Schnieder of the University of Washington, at the first URL below. Current PRT news is available at the second URL below. The energy use shown in Box 12 represents the average of several developers’ estimates.

1. <http://faculty.washington.edu/jbs/itrans/>. Accessed June 4, 2005.

2. <http://www.acprt.org/PRTNews.cfm>. Accessed June 4, 2005.

77 Amtrak’s Northeast corridor is the only electrified part of the intercity rail system in North America. About 2.63 billion passenger-kilometres (pkm) were performed in this corridor in 2000 and about 6.34 billion pkm in the rest of the U.S. system (this author’s estimates from various sources, notably Report No. GAO/RCED-96-144 by the U.S. General Accounting Office, *Northeast Rail Corridor: Information on Users, Funding Sources, and Expenditures*, 1996, at the first URL below, and Table 9.12 of Davis SC, Diegel SW, *Transportation Energy Data Book 23*, Oak Ridge Tennessee: Oak Ridge National Laboratory, 2003, at the

second URL below). According to Table A.16 of the second source, 470,170,000 kilowatt-hours of electricity and 94,968,000 U.S. gallons of diesel fuel were used respectively to provide this service.

1. <http://www.gao.gov/archive/1996/rc96144.pdf>. Accessed June 4, 2005.

2. <http://www.cta.ornl.gov/data>. Accessed June 4, 2005.

78 The data in this row are derived from data on U.S. systems provided by the American Public Transportation Association (APTA), available at the URL below.

1. <http://www.apta.com/research/stats/>. Accessed June 4, 2005.

79 For generator efficiency see, for example, Wei A, *Technologies for Next Generation Turbine Systems*. Presentation at the Turbine Power Systems Conference and Condition Monitoring Workshop, Galveston, Texas, February 2002, available at the URL below.

1. <http://www.netl.doe.gov/publications/proceedings/02/turbines/wei.pdf>. Accessed December 23, 2004.

80 For the efficiency of electrolysis, see Page 171 of the source detailed in Note 225. Also see Box 11 and the source detailed in Note 70.

81 According to Page 5 of Appendix 2 of the *Well to-Tank Report* (Version 1) of the program entitled *Well-to-Wheels analysis of future automotive fuels and powertrains in the European context*, available for download (not viewing) at the URL below, extraction, transport, refining, distribution, and dispensing of gasoline typically require energy equivalent to 14% of the energy in the delivered gasoline.

1. <http://ies.jrc.cec.eu.int/Download/eh/31>. Accessed June 4, 2005.

82 The freight transport data in Box 13 are from Høyer K and eight others, *Energy in Transport of Goods. Nordic Examples*. Report from Phase I of the European commission's SAVE project, available at the URL below. In Finland, electric freight trains appear to use less than one third of the operational energy per tonne-kilometre (tkm) used by comparable diesel freight trains, which in turn use less than half of the energy used by trucks.

1. <http://www.ecotraffic.se/pdf/et.pdf>. Accessed June 4, 2005.

83 According to Calgary Transit, power equivalent to that used by the trains is purchased from 12 wind turbines in southern Alberta and sent to the grid. See the URL below.

1. http://www.calgarytransit.com/environment/ride_d_wind.html. Accessed June 4, 2005.

84 For links to sources about PRT, see Note 76. For a contrary view on PRT see the URL below.

1. <http://www.avidorstudios.com/PRTisaJoke.html>. Accessed June 4, 2005.

85 See Brissett J, SkyWeb designer leaves Duluth company. *Duluth News Tribune*, March 3, 2005, available at the URL below.

1. <http://www.duluthsuperior.com/mld/duluthsuperior/business/11039129.htm?template=contentModules/printstory.jsp>. Accessed June 4, 2005.

86 For information about the EV-1 protest, see Marquez J, California vigil for GM green car. *Globe & Mail*, March 17, 2005. Also see the Web site of the Electric Auto Association at the second URL below. For information about electric vehicles in Canada, see the Web site of the Centre d'expérimentation des véhicules électriques du Québec (CEVEQ) at the second URL below.

1. <http://www.eaaev.org/>. Accessed June 4, 2005.

2. <http://old.ceveq.qc.ca/>. Accessed June 4, 2005.

- 87 For the resolution of the challenge to the California ZEV legislation, see Automakers Drop Challenge of California Auto Plan, *Environment News Service*, August 13, 2003, at the URL below.
1. <http://www.climateark.org/articles/reader.asp?linkid=24937>. Accessed June 4, 2005.
- 88 For the fate of TH!NK, Ford's electric vehicle, see the URL below.
1. <http://biz.yahoo.com/ic/104/104119.html>. Accessed May 26, 2005.
- 89 The data on Canada are from the source detailed in Note 48.
- 90 The world's largest passenger liner, the *Queen Mary 2*, launched in 2004, has four diesel engines and two gas turbines, all producing electricity. Propulsion depends on electric motors in four submersed 'pods', two fixed and two movable for precise steering. Cargo ships rely on a much simpler arrangement: one or two massive diesel engines each driving a massive propeller.
- 91 This information is from Issue No. 3 of the Centre for Sustainable Transportation's *Sustainable Transportation Monitor*, available at the URL below.
1. <http://www.cstctd.org>. Accessed June 4, 2005.
- 92 Box 16 is taken from Table II of Corbett JJ, Marine transportation and energy use. *Encyclopedia of Energy, Volume 3*, Elsevier Inc, New York, pp. 745-758, 2004.
- 93 See Chart 3.2.1 of *EU Energy & Transport in Figures 2004*, Brussels, Belgium: European commission, Directorate General for Energy and Transport, February 2005, available at the URL below.
1. http://europa.eu.int/comm/dgs/energy_transport/figures/pocketbook/2004_en.htm. Accessed June 4, 2005.
- 94 The data on Canadian shipping are from Pages 110-111 of the source detailed in Note 48.
- 95 It's hard to find data on marine operating costs. One source suggests that "cost of fuel as a proportion of total running costs rose from 10 per cent in 1900 to between 25 and 60 per cent by 2000". (See the first URL below.) Another source, at the second URL below, stated, "A thorough analysis of the costs of operation of the ship, including capital costs, operating and repair costs, and financing, shows that the overwhelming cost driver for high speed ocean transportation is the cost of petroleum-based fuel for the ships." The source detailed in Note 92 included the following: "More than any other transportation mode, most modern shipping activity is designed to minimize fuel consumption because it helps minimize operating costs".
1. <http://www.newscientist.com/channel/mech-tech/mg18524881.600>. Accessed June 4, 2005.
2. http://www.ccdott.org/Deliverables/1998/UofA2311_%202312/UofA%2023112312.pdf. Accessed June 4, 2005.
- 96 For U.S. domestic shipping, see Table 9.5 of the *Transportation Energy Data Book*, detailed in Note 58. There it can be seen that energy use per tonne-kilometre (represented as BTU/ton-mile in the table) has varied considerably over the last 35 years, but rose quite sharply during the late 1990s. See also Figure 8 of Michaelis L, *Special issues in carbon/energy taxation: marine bunker fuel charges*. Organization for Economic Cooperation and Development, Paris, 1997, available at the URL below, which suggests that the energy intensity of "global shipping" fell sharply in the early and mid- 1970s and remained more or less constant until the mid-1990s.

1. [http://www.oilis.oecd.org/oilis/1997doc.nsf/43bb6130e5e86e5fc12569fa005d004c/c1f21ba9fba8d907802565e700470dc8/\\$FILE/02E88855.DOC](http://www.oilis.oecd.org/oilis/1997doc.nsf/43bb6130e5e86e5fc12569fa005d004c/c1f21ba9fba8d907802565e700470dc8/$FILE/02E88855.DOC). Accessed June 4, 2005.

⁹⁷ For example, according to Transport Canada's *T-facts* service, available at the URL below, the share of international freight handled by Canadian ports that was containerized increased from 4.2% in 1983 to 8.2% in 2001. Containers handled increased from 950,000 TEUs (twenty-foot equivalent units) in 1983 to 2,674,000 TEUs in 2001. Each TEU represented 8.25 tonnes of freight in 1983 and 8.79 tonnes in 2001. According to *Shipping in Canada 2003*, Statistics Canada, Ottawa, 2005, the number of international TEUs handled at major Canadian ports had increased further from 2,674,000 in 2001 to 3,375,000 in 2003, i.e., 3.6 times the 1983 total.

1. http://www.tc.gc.ca/pol/en/T-Facts3/Statmenu_e.asp?type=pu&file=marine&Lang=. Accessed, June 4, 2005.

⁹⁸ According to one source (at the first URL below), "One of the main aspects of container shipping is just-in-time delivery. This is the background for the continuing trend towards higher speed and more reserve power to maintain speed even in rough weather. The employment of fast container ships for short sea container transport and for special services across the oceans is gaining acceptance." According to *Propulsion Trends in Container Vessels*, MAN B&W Diesel, Copenhagen, 2005, at the second URL below, "... the increase in ship size has been followed by a corresponding demand for higher design ship speeds". According to McKesson CB, *Alternative Powering for Merchant Ships*, Center for Commercial Deployment of Transportation Technologies, California State University, Long Beach, 2000, at the third URL below, "The change in ship size does not in itself explain the substantial increase in the average engine power seen in recent years. Hence, it can be assumed that the design speed has increased. Increase in average engine size is an indication of a changed demand pattern toward higher powered ship types". Corbett, in the source detailed in Note 92, noted that "Although container ships are not often as large as tankers, they have much larger power plants to accommodate greater vessel speeds" (p. 747). The greater installed power is illustrated in Box 16. Corbett also noted that "most ships carry loads that average 50-65% [of] capacity or less" (p. 755). The forgoing suggests there is considerable scope for reducing fuel use by reducing speeds (also see Note 99) and by better loading.

1. <http://amchouston.home.att.net/cs.htm>. Accessed June 4, 2005.

2. <http://www.manbw.com/files/news/files/4672/P9028.pdf>. Accessed June 4, 2005.

3. http://www.ccdott.org/Deliverables/2000/task2.9.1/task2.9.1_1.pdf. Accessed June 4, 2005.

⁹⁹ According to material produced by the United States Naval Academy, the relationship between hull resistance and ship's speed varies with the n th power of the speed, where n is 2 at low speeds and as high as 5 at high speeds. "Therefore the horsepower required can be proportional up to the ship speed raised to the sixth power!" Wind resistance, by contrast, generally varies with the square of the vehicle speed.

1. <http://www.usna.edu/NAOE/courses/en200/ch07.pdf>. Accessed June 4, 2005.

¹⁰⁰ For information on renewed interest in wind propulsion for ships, see the first source detailed in Note 95.

¹⁰¹ For a discussion of the use of these fuels, see Brooks MR, Water Transport Systems and Port Developments, in *Transportation Planning and Engineering in Encyclopedia of Life Support Systems (EOLSS)*, EOLSS Publishers, Oxford, UK, 2003.

¹⁰² Information about the *Queen Mary 2* is in Note 90.

- 103 As noted in connection with Tables 2.12, and 2.13 of *Transportation Energy Data Book*, detailed in Note 58, “Great care should be taken in comparing modal energy intensity data among modes”. These tables report for the U.S. that urban transit buses use more energy per passenger-kilometre than automobiles or commercial aviation. This arises in part because of the low reported average occupancy of these buses: 9.1 passengers per bus. The typical U.S. transit bus has 35-40 seats. Worldwide, the picture is more like that in Figure 8-4 of the IPCC source detailed in Note 109, which shows buses, trams, and trains as being generally much less energy intensive than cars and planes, with the intensities of the last two overlapping greatly according to vehicle type, distance travelled, and, above all, what the IPCC report describes as the critical matter of load factor. Also see Nielsen SK, *Air travel, lifestyle, energy use and environmental impact*. Technical University of Denmark, Ph.D. dissertation, September 2001, at the URL below, which contains a rich discussion of aviation fuel use including comparisons with other modes.
1. http://phd.dtv.dk/2001/byg/s_k_nielsen.pdf. Accessed June 4, 2005.
- 104 See Adams M, Uneasy airlines anticipate \$60-a-barrel oil. *USA Today*, March 6, 2005, available at the URL below.
1. http://www.usatoday.com/travel/flights/2005-03-06-jetfuel-usat_x.htm. Accessed June 4, 2005.
- 105 See Table 9.2 of the source detailed in Note 58. The estimated contributions to reduced fuel use per passenger- or tonne-kilometre are based on the data in this table, assuming one ton of freight to be equivalent to 10 passengers.
- 106 For a review of prospects for reductions in aviation fuel use see *The Environment Effects of Civil Aircraft in Flight*. London, UK: Royal Commission on Environmental Pollution, 2002, available at the URL below. See also Lee J, The potential offered by aircraft and engine technologies. In Thomas C et al (eds.), *Towards Sustainable Aviation*, Earthscan, London UK, 2003, pp. 162-178.
1. <http://www.rcep.org.uk/avreport.htm>. Accessed June 4, 2005.
- 107 For a discussion of the impacts of aviation on the global climate see Lee D, Raper D, The global atmospheric impacts of aviation. In Thomas C et al (eds.), *Towards Sustainable Aviation*, Earthscan, London UK, 2003, pp. 77-96. According to Lee and Raper, ozone is formed at this height because the high temperature causes the nitrogen and oxygen in the air to combine to form first nitric oxide and then nitrogen dioxide (NO₂), collectively known as nitrogen oxides. NO₂ catalyzes production of ozone, essentially through speeding up a naturally occurring process. The process breaks down another greenhouse gas in the atmosphere, methane, but not in sufficient quantities to offset the additional greenhouse effect provided by the added ozone. The net result is an increase in radiative activity (global warming effect).
- 108 According to a report by the U.S. National Aeronautics and Space Administration (NASA), aircraft constraints and consequent formation of cirrus clouds could have been responsible for nearly all of the warming observed over the United States from 1975-1995. (See the URL below.) When aviation was curtailed over the United States for three days from September 11, 2001, the diurnal temperature range increased by more than 1°C, attributed to absence of contrails. (See Travis DJ, Carleton AM, Lauritsen RG, Contrails reduce daily temperature range. *Nature*, 418, 601, 2002.)
1. http://www.nasa.gov/home/hqnews/2004/apr/HQ_04140_clouds_climate.html. Accessed June 4, 2005.

- 109 See Penner JE et al (eds), *Aviation and the Global Atmosphere, A Special Report of IPCC Working Groups I and III*. Cambridge University Press, Cambridge UK, 1999. This document is available at the URL below.
1. <http://www.grida.no/climate/ipcc/aviation/>. Accessed June 4, 2005.
- 110 See, for example, the source detailed in Note 107.
- 111 For the IATA news release, see the URL below.
1. <http://www.iata.org/pressroom/pr/2005-01-31-02.htm>. Accessed June 4, 2005.
- 112 For a comment on aviation in India, see Mukherji B, Affluent Indians holiday abroad as air fares tumble. *Globe & Mail*, March 19, 2005, at the URL below.
1. <http://www.theglobeandmail.com/servlet/ArticleNews/TPStory/LAC/20050319/INDIAN19/TPTravel/>. Accessed June 4, 2005.
- 113 See *FAA Aerospace Forecasts: Fiscal Years 2005-2016*, Washington DC: Federal Aviation Administration, March 2005, available at the URL below.
1. http://www.api.faa.gov/forecast05/Forecast_for_2005.htm. Accessed June 5, 2005.
- 114 For the projection of the Greater Toronto Airport Authority, see the URL below.
1. <http://www.gtaa.com/Index.aspx?Sid=Node1/Node1.2&Tpl=1>. Accessed June 4, 2005.
- 115 See the table in Transport Canada *T-Facts* Web site, detailed in Note 97.
- 116 See Boeing's *Current Market Outlook 2004*, available at the URL below.
1. <http://www.boeing.com/commercial/cmo/2-1.html>. Accessed June 4, 2005.
- 117 See Crowded skies: Why are so many airlines starting up? *The Economist*, April 22, 2004.
- 118 See Simon B, Jetsgo collapses in face of high fuel costs. *Financial Times (UK)*, March 11, 2005.
- 119 See Gordon DJ, Blaza A, Sheate WR, A Sustainability risk analysis of the Low Cost Airline sector. *World Transport Policy & Practice*, 11, 13-33, 2005. (This article is available at the URL below.)
1. <http://www.eco-logica.co.uk/wtpp11.1.pdf>. Accessed June 4, 2005.
- 120 See Low-cost founding fathers: How cheap air flights are bringing Europeans together. *The Economist*, January 27, 2005.
- 121 This price conservatively assumes a fuel cost of 50¢ a litre and a rate of use of five litres per 100 passenger-kilometres.
- 122 In the U.S., where five 'legacy' carriers are in bankruptcy protection, pension funds are insured against company bankruptcy by a federal agency, the Pension Benefit Guaranty Corporation. PBGC is funded by a per-capita assessment on each protected employee. It moved from a US\$8 billion surplus in 2001 to a \$23 billion deficit in 2004, largely the result of the airline industry's crisis, according to Will G, A pension crisis that only broadens, *Washington Post*, January 16, 2005. PBGC's per-capita assessment is being increased, thereby providing a subsidy to part of the aviation industry by all protected employees. Recently United Airlines won permission to terminate its plans, "paving the way for the largest pension de-

fault in U.S. corporate history” (See Carey S, US Airways, America West closing in on merger agreement, *Globe & Mail* [from the *Wall Street Journal*], May 16, 2005.)

- ¹²³ For further discussion of this point, see Perl A, Patterson J, Will Oil Depletion Determine Aviation’s Response to Environmental Challenges? *Annals of Air and Space Law*, 29, 259-273, 2005.
- ¹²⁴ For the TUI scenario work, see the URL below.
1. http://www.tui.com/en/konzern/tui_umweltmanagement/mobilitaet_umwelt/interview_mob.html, Accessed June 4, 2005.
- ¹²⁵ It’s hard to find comparative data on fuel use by airships and regular aircraft. One estimate assumes that an airship travelling at 161 kilometres per hour carrying 84 tonnes would use 2,400 litres of fuel an hour (Prentice B, Thompson J, *Airship Fuel Tankers for Northern Resource Development: A Requirements Analysis*. University of Manitoba Transport Institute. Presentation at the annual conference of the Canadian Transportation Research forum, Ottawa, Ontario, May 2003, at the first URL below.) This appears to be of the same order of fuel use, corrected for speed, as what may soon be the most fuel-efficient jet plane, the Airbus 380, which would use about 280,000 litres of fuel to carry 150 tonnes over 10,400 kilometres. Both are equivalent to about 5.5 tonne-kilometres per litre of fuel or, at the rate of six passengers per tonne, about three litres per 100 passenger-kilometres.
1. http://www.umanitoba.ca/transport_institute/publications/Publications/CTRF03_Airships.pdf. Accessed June 4, 2005.
2. http://www.aviationboom.com/features/feature_A380.shtml. Accessed June 4, 2005.
- ¹²⁶ For some information about the use of biofuels for aviation, see the source at Note 217.
- ¹²⁷ See Gillen DW, Morrison WG, Stewart C, *Air Travel Demand Elasticities: Concepts, Issues and Measurement*. Department of Finance, Government of Canada, January 2003, available at the URL below.
1. http://www.fin.gc.ca/consultresp/Airtravel/airtravStdy_e.html. Accessed June 4, 2005.
- ¹²⁸ See Patterson J, Perl A, The TGV Effect: A Potential Opportunity for Reconciling Sustainability With Aviation. *World Transport Policy and Practice*, 5, 39-45, 1999. See also Janic M, The potential for modal substitution. In Thomas C et al (eds.), *Towards Sustainable Aviation*, Earthscan, London UK, 2003, pp. 131-148.
- ¹²⁹ See Note 102 and associated text.
- ¹³⁰ For a good discussion of these topics, see Hesse M, Rodrigue J-P, The transport geography of logistics and freight distribution. *Journal of Transport Geography*, 12, 171-184, 2004.
- ¹³¹ The diagram in Box 17 is from Kaiper GV, *U.S. Energy Flow Trends – 2002*, U.S. Department of energy, Lawrence Livermore Laboratory, University of California, June 2004.
1. <http://eed.llnl.gov/flow/pdf/ucrl-tr-129990-02.pdf>. Accessed June 3, 2005.
- ¹³² What this means specifically is that the last transaction on the New York Mercantile Exchange (NYMEX) for next-month delivery of light, sweet oil (i.e., easy to stir and low in sulphur) of a grade known as West Texas Intermediate on April 1, 2005, was at a per-barrel price of US\$57.27. On April 4, offers above \$58.00 were accepted, but the closing price was lower.

- ¹³³ A decline had been anticipated: see, for example Cattaneo C, Bearish signs abound for crude: Fundamentals, interest rates point to price drop. *Financial Post (Toronto)*, March 28, 2005. Claudia Cattaneo provided “six reasons crude’s upward trajectory could stall, and even go south”: (i) higher interest rates that make other investments [that into crude oil futures] more attractive; (ii) slower economic growth that reduces oil use; (iii) reduced rate of oil use by China; (iv) high inventories of oil products; (v) the vanishing ‘fear’ premium, because of a generally calming political situation in oil-producing countries; and (vi) conservation and increased efficiency that will “at some point ... also kick in”. A more fundamental reason for a fall in prices could be that for the next few years “a flood of new production is set to hit the market” (Skrebowski C, Oil field mega projects 2004, *Petroleum Review*, 18-20, January 2004.) However, after that there is a near-void, the result of a slowing down in discoveries. Skrebowski notes the work of IHS Energy to the effect of the 28 discoveries of over 500 million barrels of oil equivalent in 2000-2002, 17 were in 2000, eight were in 2001, and three were in 2002.
- ¹³⁴ For example, as recently as September 2004, when the NYMEX price characterized in Note 132 was \$44.61, the International Energy Agency was reported as saying that prices were not likely to stay above \$40. (Price of crude soars on U.S. worries. *Globe & Mail*, September 10, 2004.) In December 2004, the chief executive of BP was reported as saying that the price of crude oil was “set to fall back to US\$30 per barrel as fears of a supply shortage dissipate”. (Brieger P, Oil will settle back to US\$30: BP chief. *Financial Post (National Post)*, December 11, 2004.) Similarly, the Canadian Energy Research Institute’s May 2005 *CERI Energy Insight*, available at the URL below, argues that the price of a barrel of oil will average US\$47.50 for 2005. CERI attributes the high prices to a “fear premium” that adds almost \$30 to a price based on “market fundamentals” of \$21.50-\$25.50 a barrel. (The average daily closing price for January-May 2005 was \$50.42, and the June 3 price was \$55.03.)
1. <http://www.ceri.ca/documents/CERIInsight-May2005.pdf>. Accessed June 3, 2005.
- ¹³⁵ Also relevant is what appears to be a sharp reduction in US dollar holdings by oil exporters, in favour of euros and sterling. (See Johnson S, Blas J, Opec sharply reduces dollar exposure. *Financial Times* (London), December 6, 2004.) The ability of the U.S. to sustain its large current account deficit depends on continued substantial foreign holdings of dollars, many for purchasing oil, which is mostly traded in dollars. There has been speculation that the U.S. invasion of Iraq was prompted by an Iraqi decision to trade its oil in euros, and that Russia and Iran might also begin selling oil for euros rather than dollars
- ¹³⁶ Oil prices in Box 18 are from the U.S. Energy Information Administration at the first URL below, and from NYMEX at the second URL below. Dollar to euro conversions are at the third URL below.
1. <http://www.eia.doe.gov/emeu/international/Crude1.xls>. Accessed June 4, 2005.
2. http://www.nymex.com/jsp/markets/lSCO_fut_hist.jsp?. Accessed June 4, 2005.
3. <http://www.oanda.com/convert/fxhistory>. Accessed June 4, 2005.
- ¹³⁷ A good account of the positions of the ‘depletionists’ and antidepletionists’ is in the document *Is the world running out of oil? A review of the debate*. Department of Transport and Regional Services, Government of Australia, Canberra, February 2005, available at the URL below. The report concludes by noting a major point of agreement between the two “schools of thought”: the need to improve the quality, reliability, and transparency of oil reserve data.
1. <http://www.btre.gov.au/docs/workingpapers/wp61/wp61.pdf>. Accessed June 4, 2003.
- ¹³⁸ A recent thorough exposition of what is sometimes known as the ‘cornucopian’ view is Huber PW, Mills MP, *The Bottomless Well: The Twilight of Fuel, the Virtue of Waste, and*

Why We Will Never Run Out of Energy. New York: Basic Books, 2005. Other recent sources expounding such a position are Lynch MC, The New Pessimism about petroleum Resources: Debunking the Hubbert Model (and Hubbert Modelers). *Minerals & Energy*, 18, 21-32, 2003, and Adelman MA, The Real Oil Problem, *Regulation*, 27, 16-21, 2004.

- ¹³⁹ See Dusseault MB, Flawed reasoning about oil and gas. *Nature*, 386, 12, 1997.
- ¹⁴⁰ This view is currently most associated with geologist Colin Campbell. See his *The Essence of Oil & Gas Depletion*, Multi-Science Publishing Company: Bentwood (UK), 2003. See also Deffeyes KS, *Hubbert's Peak: The Impending World Oil Shortage*. Princeton University Press, 2001, and Goodstein D, *Out of Gas: The End of the Age of Oil*, Norton: New York, 2004.
- ¹⁴¹ Historically, concern about oil production peaks began with geophysicist M. King Hubbert, who accurately predicted the U.S. production peak. His work is described in the book by Deffeyes detailed in Note 140.
- ¹⁴² Data on oil production are from *BP Statistical Review of World Energy*, available at the URL below.
1. <http://www.bp.com/subsection.do?categoryId=95&contentId=2006480>. Accessed June 4, 2005.
- ¹⁴³ Box 19 is Figure 20 in Aleklett K, *IEA accepts peak oil: An analysis of Chapter 3 of the World Energy Outlook 2004*, available at the first URL below (Web site of the Uppsala Hydrocarbon Depletion Group). The figure suggests that production of liquid hydrocarbons suitable for conversion into transport fuels will peak before 2010. Some estimates point to earlier peaks, e.g., in 2005, as projected in Deffeyes KS, *Hubbert's Peak: The Impending World Oil Shortage*. Princeton University Press, 2001. Others point to later peaks, e.g., in 2018-2023, as projected in White N, Thompson M, Barwise T, Understanding the thermal evolution of deep-water continental margins, *Nature*, 426:6964, 324-333, 2003. Among projections of later production peaks are those of the U.S. Energy Information Administration (EIA), which suggests production will continue rising beyond 2025 (*International Energy Outlook 2004*, Washington DC, 2004, available at the second URL below) and the International Energy Agency (IEA), discussed here (see Notes 145-147 and associated text).
1. <http://www.peakoil.net/uhdsg/weo2004/TheUppsalaCode.html>. Accessed June 4, 2005.
2. <http://www.eia.doe.gov/oiaf/ieo/>. Accessed June 4, 2005.
- ¹⁴⁴ Low oil company investment rates are a theme of *The Economist's* 'Survey of Oil', April 30, 2005.
- ¹⁴⁵ The quote is from Page 29 of the source detailed in Note 12.
- ¹⁴⁶ This is the 'Low resource case' in Table 3.4 on Page 102 of the source detailed in Note 12.
- ¹⁴⁷ Box 20 is Figure 3.20 on Page 103 of the source detailed in Note 12.
- ¹⁴⁸ See, for example, the first source detailed in Note 143.
- ¹⁴⁹ See Figure 3.14 on Page 97 of the source detailed in Note 12.
- ¹⁵⁰ Box 21 is from Slide 4 of a presentation by Harry J. Longwell, Executive VP, Exxon Mobil Corporation at the Offshore Technology Conference, Houston, Texas, May 7, 2002, available at the first URL below. Box 21 shows oil discoveries only until 2000 and may suggest

they were then on the rise again after a long decline. Data for subsequent years show this is not the case. According to Smith MR, *World Oil Supply Report*, 3rd edition, Douglas-Westwood Ltd., 2004, as reported in Anon, Study: World oil forecast beset with reserves shortfalls. *Oil & Gas Journal*, April 12, 2004, discoveries in 2000, 2001, and 2002 were respectively 13.05, 4.02, and 3.34 billion barrels. A February 2004 editorial in the industry journal *Petroleum Review* described the 2003 results as “little short of horrifying”, noting that it may have been the first year since the 1920s in which there were no large oil discoveries at all (see the second URL below).

1. http://www.exxonmobileurope.com/Corporate/Newsroom/SpchsIntvws/Corp_NR_SpchIntrvw_Houston_070502.asp. Accessed June 4, 2005.

2. <http://www.energyinst.org.uk/index.cfm?PageID=920>. Accessed June 4, 2005.

- ¹⁵¹ See Oster S, Big Oil Companies Slow New Exploration. Dow Jones Newswire at *CNN Money*, January 17, 2005.
- ¹⁵² Berenson A, An Oil Enigma: Production Falls even as Reserves Rise. *New York Times*, June 12, 2004.
- ¹⁵³ The data for 1965-2003 in Box 22 are based on the table on Page 9 of the June 2004 issue of the *BP Statistical Review of World Energy*, detailed in Note 142. The data for 2004 are based on tables on Pages 4 and 5 of a recent *Monthly Oil Market Report* of the International Energy Agency (February 10, 2005, available at the URL below). The *Report* for May 2005 showed that China’s imports of oil products were lower in January 2005 than the average of any quarter in 2004, leading to comment that moderation of oil consumption was occurring. However, imports for February were higher than any of these averages, and imports for March were higher than two of them.
1. <http://omrpublic.iea.org/currentissues/full.pdf>. Accessed June 4, 2005.
- ¹⁵⁴ The data on China’s consumption and imports of oil and oil products are from the sources detailed in Note 153.
- ¹⁵⁵ Details about the IEA workshop and copies of most of the presentations made at it are available at the URL below.
1. http://www.iea.org/textbase/work/2005/oil_demand/FinalAgenPresentations.htm. Accessed June 4, 2005.
- ¹⁵⁶ *Saving Oil in a Hurry*. International Energy Agency: Paris, 2005.
- ¹⁵⁷ See, for example, McCarthy S, Syncrude chief extols oil sands to U.S. market. *Globe & Mail*, February 9, 2005. This article was accompanied by a table indicating that of the world nine top oil producers only Canada is expected to have a higher rate of production in 2015 than in 2003. Two more recent ‘front page’ treatments have been: (1) Cattaneo C, Oil tapping out: Crude shortage looms: Discoveries dwindle: Global production seen falling in two years. *Financial Post (National Post)*, April 21, 2005; and (2) McKenna B, Crude Awakening. Oil supplies peak this year. What’s next? *Globe & Mail*, May 21, 2005. The second article introduced a seven-day series of articles on numerous aspects of energy and related futures.
- ¹⁵⁸ See, for example, CIBC World Markets *Occasional Report #53*, April 13, 2005, available at the URL below.
1. http://research.cibcwm.com/economic_public/download/occ_53.pdf. Accessed June 4, 2005.

- 159 The workshop program is at the URL below.
1. <http://www.cge.uevora.pt/asp02005/program.php>. Accessed June 4, 2005.
- 160 Cattaneo C, Oil plan keys on supply crunch: Depletion protocol focus of global leaders' meeting. *Financial Post (National Post)*, May 16, 2005.
- 161 The text of the Oil Depletion Protocol in Box 25 was taken from the URL below.
1. <http://www.odac-info.org/bulletin/DepletionProtocol.htm>. Accessed June 4, 2005.
- 162 The U.S. Energy Information Administration puts the matter in this way: "According to *Oil and Gas Journal*, Canada had a reported 178.8 billion barrels of proven oil reserves in 2005, second only to Saudi Arabia. However, the bulk of these reserves (over 95%) are oil sands deposits in Alberta. The inclusion of oil sands in official reserve estimates is not without controversy, because oil sands are much more difficult to extract and process than conventional oil." (See the URL below.) The controversial nature of the reclassification, apparently initiated by Canada, is evidenced in Reynolds DB, The economics of oil definitions: the case of Canada's oil sands. *OPEC Review*, 29, 51-73, 2005.
1. <http://www.eia.doe.gov/emeu/cabs/canada.html>. Accessed June 4, 2005
- 163 The data in Box 24 are from the BP source detailed first in Note 147.
- 164 The NAFTA clause is Article 605a, available at the Web site of the NAFTA Secretariat at the URL below.
1. http://www.nafta-sec-alena.org/DefaultSite/index_e.aspx?DetailID=78. Accessed June 4, 2005.
- 165 Withdrawal is provided for in Article 2205 of NAFTA, available at the source detailed in Note 164.
- 166 See *Advancing Canadian Interests in the United States: A Practical Guide for Canadian Public Officials*, February 2005, available at the URL below.
1. http://www.myschool-monecole.gc.ca/Research/publications/html/p127/9_e.html. Accessed June 4, 2005.
- 167 See Bennett S, American and Canadian assessments of NAFTA: Opinion on continental policy and its drivers. *American Behavioral Scientist*, 47, 1285-1318, 2004.
- 168 In converting barrels to litres, the factor on Page 41 of the BP source detailed first in Note 147 was used (159 litres per barrel). The per-capita estimations made use of population data from Statistics Canada at the first URL below.
1. <http://www.statcan.ca/english/freepub/98-187-XIE/pop.htm#53>. Accessed June 4, 2005.
- 169 See Romero S, China emerging as U.S. rival for Canada's oil. *New York Times*, December 23, 2004. See also Brethour P, Canadian oil could be headed for China under latest deal. *Globe & Mail*, June 1, 2005.
- 170 These data are from Statistics Canada, Oil and gas extraction industry: Volume and value of marketable production. *The Daily*, October 26, 2004, available at the URL below.
1. <http://www.statcan.ca/Daily/English/041026/d041026f.htm>. Accessed June 4, 2005.
- 171 This estimate of the relative intensities of GHG emissions from production synthetic and conventional crude oil is the author's, based on two sources. One is Table G.4 on Page 83 of *Oil and Natural Gas Industry Foundation Paper* prepared by the industry for the National Climate Change Secretariat, September 1998, and available at the first URL below. There,

production conventional and synthetic oil was said to be responsible respectively for 360 and 817 kilograms of carbon dioxide per cubic metre of product. The other source is Figure 7.1 on Page 62 of *Canada's Oil Sands: Opportunities and Challenges to 2015*. Ottawa, Ontario: National Energy Board, May 2004, available at the second URL below.

1. http://www.nccp.ca/NCCP/pdf/indus_oil.PDF. Accessed June 4, 2005.

2. http://www.neb-one.gc.ca/energy/EnergyReports/EMAOilSandsOpportunitiesChallenges2015/EMAOilSandsOpportunities2015Canada2004_e.pdf. Accessed June 4, 2005.

¹⁷² For a discussion of the water requirements for oil sands development, see Griffiths M, Woynillowicz D, *Oil and Troubled Waters*, Pembina Institute, Drayton Valley, Alberta, April 2003, available at the URL below.

1. <http://www.pembina.org/pdf/publications/OilandTroubledWaters.pdf>. Accessed June 4, 2005.

¹⁷³ In the second source detailed in Note 171 (the 2004 National Energy Board document), the cost of crude oil is projected to average US\$18 per barrel and this is estimated to be a price high enough to allow substantial expansion of production from Alberta's oil sands. A recent announcement by Suncor concerning proposed oil sands development noted that the price of oil needs to be US\$28 or higher to provide an acceptable return on the investment. (See Brethour P, Suncor set on oil sands expansion. *Globe and Mail*, March 14, 2005.)

¹⁷⁴ Box 25 is based on Table C of Perry GL, *The War on Terrorism, the World Oil Market and the U.S. Economy*. Analysis Paper #7. Washington DC: The Brookings Institution, October 24, 2001, available at the first URL below. Some of the assumptions are in the baseline column ('0% shortfall'). Also assumed is a contribution of crude oil costs of \$0.31 to the present gasoline price of \$0.85, based on information from Petro-Canada at the second URL below. For simplicity, taxes and other costs are assumed not to change. Numbers have been rounded to discourage the impression that this is an exercise in accurate estimation.

1. <http://www.brookings.edu/views/papers/perry/20011024.htm>. Accessed June 4, 2005.

2. <http://www.petro-canada.ca/eng/prodserv/fuels/8737.htm>. Accessed June 4, 2005.

¹⁷⁵ The CIBC source is detailed in Note 158.

¹⁷⁶ Greene DL, *Why save oil in a hurry?* Presentation at the conference entitled 'Managing Oil in Transport', International Energy Agency, Paris, March 2005, available at the URL below. When the price elasticity of demand is -0.12, a 10 per cent increase in price results in a 1.2 per cent reduction in consumption.

1. http://www.iea.org/Textbase/work/2005/oil_demand/Oiltransportwkshp/pdf/files-day1/greene1.pdf. Accessed June 4, 2005.

¹⁷⁷ See Cooper JCB, Price elasticity of demand for crude oil: estimates for 23 countries. *OPEC Review*, 27, 1-8, 2003.

¹⁷⁸ Analysts are turning to this task, as evidenced in *Oil Market Developments and Issues*, International Monetary Fund, March 2005, available at the URL below. This paper includes a detailed analysis of the economic impact of an increase in the crude oil price to \$80 during 2005.

1. <http://www.imf.org/external/np/pp/eng/2005/030105.pdf>. Accessed June 4, 2005.

¹⁷⁹ See the table on Page 443 of the source detailed in Note 145.

¹⁸⁰ Vancouver-based Westport Innovations Inc. is a pioneer in the development of diesel engines that can use CNG or LNG. The company's Web site is at the URL below.

1. <http://www.westport.com/>. Accessed June 4, 2005.

- 181 Natural gas serves as a fuel for stationary fuel cells. See the first URL below. Indeed, the first device called a fuel cell (not the first fuel cell) used coal gas—also, like natural gas, chiefly methane—as a fuel. See the second URL below.
1. http://www.pnl.gov/fta/5_nat.htm. Accessed June 4, 2005.
 2. <http://www.fuelcelltoday.com/FuelCellToday/EducationCentre/EducationCentreExternal/EduCentreDisplay/0,1741,History,00.html>. Accessed June 4, 2005.
- 182 Confusingly, propane is also known as liquefied petroleum gas (LPG), marketed in Europe as ‘autogas’.
- 183 For information about the Fischer-Tropsch process, see the first URL below. For information about the high costs of producing such a gasoline substitute see Williams RH, Larson ED, A comparison of direct and indirect liquefaction technologies for making fluid fuels from coal. *Energy for Sustainable Development*, 7(4), 103-124, 2003, available at the second URL below. Also see Table 1 of Greene D, *An Assessment Of Energy And Environmental Issues Related To The Use Of Gas-To-Liquid Fuels In Transportation*, available at the third URL below. Notwithstanding the high costs, several oil companies are together investing US\$20 billion in a massive gas-to-liquids (GTL) plant in Qatar for the production of diesel and other liquid fuels. See Krane J, Gamble in the desert—‘Green’ diesel from natural gas could cut city smog. *Associated Press*, May 11, 2005, available at the fourth URL below.
1. <http://www.tntech.edu/chemistry/Inorganic/Chem4110/Student/01%20The%20Fischer-Tropsch%20Process.ppt>. Accessed June 4, 2005.
 2. <http://64.233.161.104/search?q=cache:m8EZUIWMGHoJ:www.iejglobal.org/ESDVol7No4/dclversussicl.pdf+%22A+comparison+of+direct+and+indirect+liquefaction+technologies%22&hl=en>. Accessed June 4, 2005.
 3. <http://www.osti.gov/energycitations/servlets/purl/14505-x2HG3w/native/14505.pdf>. Accessed June 4, 2005.
 4. <http://www.enr.com/today.html?id=7715>. Accessed May 17, 2005.
- 184 According to Amory Lovins, *Twenty Hydrogen Myths* (Rocky Mountain Institute, 2003, at the URL below), “U.S. hydrogen production is at least one-fifth and probably nearer one-third of the world total, is equivalent to ~1.8% of total U.S. energy consumption, and comes ~95% from natural gas at ~99% purity from steam reforming and associated cleanup processing”.
1. http://www.rmi.org/images/other/Energy/E03-05_20HydrogenMyths.pdf. Accessed June 4, 2005.
- 185 From Page 84 of *Bus systems for the future: Achieving sustainable transport worldwide*. Paris, France: International Energy Agency, 2002.
- 186 For an informed view that North American natural gas production may have already peaked, see the presentation by Matthew Simmons, *The Natural Gas Riddle: Why Are Prices So High? Is a Serious Crisis Underway?* at the mini-conference of the International Association for Energy Economics, Houston, Texas, December 11, 2003, available at the first URL below. See also the January 2005 report *North American Natural Gas Vision* by the three-government North American Energy working Group, available at the second URL below. The report included the following: “Gas prices are at high levels primarily because growth in demand has outstripped growth in North American gas production. For the future, increases in conventional natural gas supplies appear unlikely – production from conventional Canadian and U.S. gas basins in recent years has been flat or declining, despite historically high levels of natural gas drilling.”
1. <http://www.simmonsco-intl.com/files/IAEE%20Mini%20Conf.pdf>. Accessed June 4, 2005.
 2. <http://www.pi.energy.gov/pdf/library/NAEWGGasVision2005.pdf>. Accessed June 4, 2005.
- 187 Nikiforuk A, Life inside a science project. *Report on Business Magazine*, May 2005, available at the URL below.

1. <https://secure.globeadvisor.com/servlet/ArticleNews/story/gam/20050429/RO5ENCANA>. Accessed June 4, 2005.
- 188 The quotation is from Weissman A, *puncturing natural gas myths – Part 1*, November 21, 2003, on reviewing the U.S. National Petroleum Council’s report *Balancing Natural Gas Policy*, September 2003. The review is at the first URL below. Volume 1 of the report is at the second URL.
1. http://www.energypulse.net/centers/article/article_print.cfm?a_id=556. Accessed June 5, 2005.
 2. <http://www.npc.org/reports/ng.html>. Accessed June 5, 2005.
- 189 Canadian gas, which would move along the Mackenzie Valley, could be used almost exclusively in extracting and refining oil sands products. It is presently stalled by unsettled First Nations’ land claims and what has been described as “the ineffectiveness of the regulatory regime” (see Yedlin D, Think Mackenzie group is bluffing? Think again. *Globe and Mail* May 2, 2005). U.S. Arctic gas would move along the Alaska Highway pipeline and could be used mostly to augment U.S. supply. Potential natural gas shortages for oil sands development have recently stimulated further talk about use of nuclear energy provide the necessary heat and electricity, including electricity for the production from electrolysis of hydrogen needed to upgrade bitumen to a usable vehicle fuel. (see Brethour P, Nuclear option for oil sands. *Globe & Mail*, May 3, 2005.)
- 190 According to the first source detailed in Note 153, North America was responsible for 24% of world natural gas consumption in 2003 but had only 3% of proven natural gas reserves. The Middle East and Russia had respectively 41% and 27% of proven reserves. Natural gas can be economically shipped between continents as liquefied natural gas (LNG) when the wholesale natural gas price is above about U.S.\$3.50 per gigajoule (see the chart on Page 67 of *International Energy Outlook 2004*, detailed in Note 143). Three difficulties impede rapid expansion of LNG imports: (i) a shortage of vessels designed to carry LNG; (ii) a shortage of terminals designed to receive LNG; and (iii) movement of LNG is regarded as hazardous. On the last point consider the following from Powers B, *Assessment of Potential Risk Associated with Location of LNG Receiving Terminal Adjacent to Bajamar and Feasible Alternative Locations*, at the first URL below: “The US Coast Guard requires a two-mile moving safety zone around each LNG tanker that enters Boston Harbor, and shuts down Boston’s Logan Airport as the LNG tanker passes by. ... These extraordinary precautions are taken out of concern for spectacular destructive potential of the fire and/or explosion that might result from a LNG tank rupture.” Also of concern is terrorist action. A recent report done for the U.S Department of Energy sets out some of the risks and concerns. It was Hightower M and nine others, *Guidance on risk analysis and safety implications of a large liquefied natural gas (LNG) spill over water*. Sandia National Laboratoris, Albuquerque, New Mexico, December 2004, available at the second URL below. The report has been criticized as being selective by Raines B, Finch B, Scientists say LNG review is missing critical studies. *Mobile Register*, December 23, 2004, available at the third URL below.
1. http://www.borderpowerplants.org/pdf_docs/lng_position_paper_june2002_english.pdf. Accessed June 5, 2005.
 2. http://www.fe.doe.gov/programs/oilgas/storage/lng/sandia_lng_1204.pdf. Accessed June 5, 2005.
 3. <http://www.wildcalifornia.org/pages/page-114>. Accessed June 5, 2005.
- 191 For a good indication of the challenges posed by coalbed methane, see the article by Andrew Nikiforuk detailed in Note 187.

- 192 The quotations and other information in this paragraph is from *Gas (methane) hydrates – A new frontier*, U.S. Geological Survey, January 2005, at the URL below.
1. <http://marine.usgs.gov/fact-sheets/gas-hydrates/title.html>. Accessed May 3, 2005.
- 193 See the URL below.
1. http://www.netl.doe.gov/publications/press/2003/tl_arcticplatform.html. Accessed June 5, 2005.
- 194 See Adam D, U.S. in race to unlock new energy source. *The Guardian*, April 4, 2005, at the URL below.
1. <http://www.guardian.co.uk/life/science/story/0,12996,1451582,00.html>. Accessed June 5, 2005.
- 195 The Alberta Gas Reference Price increased almost three-fold between October 1988 and October 2004, from \$1.86 to \$5.29 per gigajoule (see the URL below).
1. <http://www.energy.gov.ab.ca/xdata/gas/refprice/monthlyref.asp>. Accessed June 5, 2005.
- 196 For a brief discussion of ‘demand destruction’, see Pages 4-5 of *Looking Ahead to 2010: Natural Gas Markets in Transition*, National Energy Board, Ottawa, August 2004, available at the URL below. According to this document, the term was coined to describe responses to high natural gas prices, although this is doubtful.
1. http://www.neb-one.gc.ca/energy/EnergyReports/EMAGasLookingAhead2010August2004_e.pdf. Accessed June 5, 2005.
- 197 The quotation is from Weissman A, *Puncturing natural gas myths – Part 2*, November 24, 2003, at the URL below.
1. http://www.energypulse.net/centers/article/article_print.cfm?a_id=557. Accessed June 5, 2005.
- 198 The natural gas consumption and price data in Box 26 are based on data available from the U.S. Energy Information Administration at the URL below, modified using population estimates from the U.S. Census Bureau. The ‘city gate’ price is the average price paid by local distribution utilities to pipeline companies. Average 2004 prices as a percentage of city gate prices were: industrial 96%; electricity generation, 84%; residential, 162%; commercial, 139%. The chart represents about 92% of total natural gas consumption. The remainder is used as vehicle fuel (0.07% of the total in 2004) and for processing and distributing the natural gas. Across the period 1997-2004, total consumption fell by 1.4% (8.4% per capita) from 644 to 635 billion cubic metres. Consumption for all end uses fell absolutely, except for electric power generation, which increased by 32%.
1. http://www.eia.doe.gov/oil_gas/natural_gas/info_glance/natural_gas.html. Accessed June 5, 2005.
- 199 Although the city gate price increased by 114% from 1999 to 2004, prices to users increased less, as follows: residential, 61%; commercial, 74%; industrial, 105%, electricity generation, 112%. (Data are from the source detailed in Note 198.)
- 200 For a comment on the efficiency of steam locomotives, see the URL below.
1. <http://www.lafn.org/~dave/trans/energy/fuel-eff-20th.html#toc1>. Accessed June 5, 2005.
- 201 See Cannon JS, *Harnessing Hydrogen: The Key to Sustainable Transportation*, at the URL below.
1. <http://www.hydrogenus.com/harness1.htm>. Accessed June 5, 2005.
- 202 For the recent rise in coal prices, see Stueck W, Soaring coal prices keep miners digging. *Globe & Mail*, April 6, 2005, and Adams T, A coal disaster. *Financial Post (National Post)*, April 29, 2005. For further information about coal prices, See the U.S. Energy Information

Administration's *Coal News and Markets*, at the URL below.

1. <http://www.eia.doe.gov/cneaf/coal/page/coalnews/coalmar.html>. Accessed June 5, 2005.

203 See Table 5.1 of the source detailed in Note 3.

204 See the source at the URL below.

1. <http://www.ualberta.ca/~jplambec/che/p101/p01264a.htm>. Accessed June 5, 2005.

205 See the source at the URL below.

1. http://wardsauto.com/ar/auto_gm_dow_begin/. Accessed June 5, 2005.

206 See the source at the URL below.

1. <http://www.personal.psu.edu/users/m/x/mxe175/Read%20at%20once.html>. Accessed June 5, 2005.

207 For a source on the Fischer-Tropsch process, see Note 183. For a discussion of South Africa's conversion of coal to vehicle fuels, see Geertsema A, *Gas to synfuels and chemicals*, at the first URL below. See also Williams RH, Larson ED, A comparison of direct and indirect liquefaction technologies for making fluid fuels from coal. *Energy for Sustainable Development*, 7(4), 103-124, 2003, available at the second URL below.

1. http://www.worldenergy.org/wec-geis/publications/default/tech_papers/17th_congress/3_1_18.asp. Accessed June 5, 2005.

2. <http://www.ieiglobal.org/ESDVol7No4/dclversussicl.pdf>. Accessed June 5, 2005.

208 For some discussion of prices of oil from coal, see Bensaid B, *Alternative Motor Fuels Today and Tomorrow*, at the first URL below. For an alternative process and price estimates, see the second URL below.

1. http://www.ifp.fr/IFP/en/files/cinfo/IFP-Panorama05_06-CarburantsalternatifsVA.pdf. Accessed June 5, 2005.

2. <http://www.dti.gov.uk/energy/coal/cfft/cct/pub/pdfs/news13.pdf>. Accessed June 5, 2005.

209 For information about coal prices see the sources detailed in Note 202.

210 For further information about China's coal liquefaction plans, see Coal liquefaction to ease oil import burden. *China Daily*, January 24, 2005, available at the URL below.

1. <http://www.china.org.cn/english/BAT/118614.htm> Accessed June 5, 2005.

211 See U.S. Department of Energy, *FutureGen: Integrated Hydrogen, Electric Power Production and Carbon Sequestration Research Initiative*. Report to Congress, March 2004, available at the URL below.

1. http://www.fe.doe.gov/programs/powersystems/futuregen/futuregen_report_march_04.pdf. Accessed June 5, 2005.

212 See Page 430 of the source detailed in Note 3.

213 See a projection of the peak in world coal production, see Vaux G, *The peak in U.S. coal production*, May 2004, at the URL below.

1. http://www.fromthewilderness.com/free/ww3/052504_coal_peak.html. Accessed June 5, 2005.

214 See *Biofuels for transport: An international perspective*. Paris, France: International Energy Agency, April 2004.

215 A recent report for the U.S. Congress by the Congressional Research Service (*Fuel Ethanol: Background and Public Policy Issues*, September 2004, available at the first URL below) noted that the U.S. market for transport fuel ethanol, comprising 2.1% of gasoline consump-

tion in 2003, is heavily dependent on federal incentives and regulations, and that the fuel ethanol industry could scarcely survive without these incentives. According to the Renewable Fuels Association, U.S. ethanol production in 2004 was 21% above production in 2003. (See the second URL below.)

1. <http://www.ncseonline.org/nle/crsreports/05jan/RL30369.pdf>. Accessed June 5, 2005.
2. <http://www.ethanolrfa.org/pr050223.html>. Accessed June 5, 2005.

- 216 The Canadian company providing leadership in lignocellulosic ethanol production is Iogen Corporation. Information about the company is available at the URL below, and well as information about the process of enzymatic conversion of the plant cellulose.
1. <http://www.ioegen.ca/>. Accessed June 5, 2005.
- 217 See Simões, AF, Shaeffer R, Espirito Santo Jr. R, *Mitigation Alternatives for CO₂ Emissions by the Air Transport Industry in Brazil*. Paper presented at the Eighth Air Transport Research Society Conference, Istanbul, Turkey, 2004.
- 218 The review is Patzek TW, Pimentel D, Thermodynamics of energy production from biomass. *Critical Reviews in Plant Sciences*, 2005, in press, available at the URL below.
1. <http://petroleum.berkeley.edu/papers/patzek/CRPS-BiomassPaper.pdf>, Accessed June 5, 2005.
- 219 See Eliasson G, *Biogas as a transportation fuel*. Paper presented at the Ökosociales Forum Österreich, Grax, Austria, January 2005, available at the URL below.
1. http://www.oesfo.at/static/mediendatenbank/root01/Veranstaltungen%20Downloads/Mitteeurop%C3%A4ische%20Biomassekonferenz%202005/Vortr%C3%A4ge/Eliasson_long.pdf. Accessed June 5, 2005.
- 220 See the source detailed in Note 217.
- 221 The company is BMW, marching to a different drummer from the rest of the automotive industry, already with a vehicle winning awards. See the URL below.
1. http://www.newratings.com/analyst_news/article_586446.html. Accessed June 5, 2005.
- 222 See, for illustration, the source detailed in Note 67.
- 223 See Note 184 on the production of hydrogen from natural gas.
- 224 Box 27 is taken from Page 4 of the document detailed in Note 211.
- 225 According to Page 119 of Committee on Alternatives and Strategies for Future Hydrogen Production and Use, National Research Council, *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs*. (Washington DC, National Academies Press, 2004), available at the URL below, the current cost of hydrogen from electrolysis is four times or more the cost of hydrogen produced from natural gas, and with anticipated future technologies will continue to be at least twice as expensive as other means of production.
1. <http://www.nap.edu/openbook/0309091632/html/119.html>. Accessed June 5, 2005.
- 226 The source in Note 225 provides a good account of distribution and storage challenges. Also see the source detailed in Note 70.
- 227 The source of the data in this paragraph is the IEA's *World Energy Outlook 2004*, detailed in Note 3.
- 228 The report is *Projected costs of generating electricity*. International Energy Agency, 2005.

- 229 See Figure 6.3 of the source detailed in Note 3.
- 230 For a discussion of this point, see Mehta M, Energy mixes and future scenarios: the nuclear option deconstructed. In Lee E, Perl A (eds.), *The Integrity Gap: Canada's Environmental Policy and Institutions*, Vancouver: UBC Press, 2003.
- 231 See two recent OECD volumes: (1) *Geological repositories: political and technical progress*. Nuclear Energy Agency, OECD, Paris, France, 2005, and (2) *Management of uncertainty in safety cases and the role of risk*. Nuclear Energy Agency, OECD, Paris, France, 2005. The first volume includes a note on Page 63 to the effect that Sweden has internalized the cost of nuclear waste disposal, perhaps the only instance of this.
- 232 See, for example, James Lovelock, Gaia must go nuclear. *Globe & Mail*, March 10, 2005. See also the testimony of Patrick Moore, Greenpeace co-founder, before a U.S. Congressional hearing, Subcommittee on Energy and Resources, April 28, 2005, available at the URL below.
1. <http://www.reform.house.gov/UploadedFiles/4.28.05%20Moore%20Testimony.pdf>. Accessed June 5, 2005.
- 233 See *Electricity Information 2002*. U.S. Energy Information Administration at the URL below.
1. <http://www.eia.doe.gov/emeu/international/electric.html#IntlCapacity>. Accessed June 5, 2005.
- 234 Box 28 is taken from Jeremy Whitlock's *Canadian Nuclear FAQ*, available at the URL below.
1. http://www.nuclearfaq.ca/cnf_sectionG.htm#uranium_supply. Accessed June 5, 2005.
- 235 See Page 10 of *Choosing a Way Forward*, Nuclear Waste Management Organization, Ottawa, 2005, at the URL below. Meanwhile, the U.S. may now be moving away from deep underground storage in favour of "a radically different storage strategy: putting the waste in huge casks that could be parked in a handful of high-security lots around the country for decades" (Walk ML, Casks gain favour as method storing nuclear waste. *New York Times*, June 5, 2005).
1. http://www.nwmo.ca/adx/asp/adxGetMedia.asp?DocID=1224,1026,20,1,Documents&MediaID=2341&Filename=NWMO_DSR_E.pdf. Accessed June 5, 2005.
- 236 For a discussion of the Swedish nuclear predicament, see the URL below.
1. <http://www.ecology.at/nni/country.php?country=Sweden> Accessed June 5, 2005.
- 237 For current industry perspectives on wind energy, visit the sites of the Canadian, American, and European Wind Energy Associations, respectively at the first, second, and third URLs below. There is also a new World Wind Energy Association, with information at the fourth URL below.
1. <http://www.canwea.ca>. Accessed June 5, 2005.
2. <http://www.awea.org>. Accessed June 5, 2005.
3. <http://www.ewea.org/>. Accessed June 5, 2005.
4. <http://www.wwindea.org/>. Accessed June 5, 2005.
- 238 See Keith DW, et al, Influence of large-scale wind power on global climate. *Proceedings of the National Academy of Sciences*, 101, 16115–16120, 2004.
- 239 For information about solar energy, see the Web site of the International Solar Energy Society at the URL below.
1. <http://www.ises.org/ises.nsf!Open>. Accessed June 5, 2005.

- 240 Nova Scotia Power operates one of three tidal power plants in the world—the Annapolis Tidal Generating Station—with information at the URL below.
 1. <http://www.nspower.ca/AboutUs/OurBusiness/PowerProduction/HowWeGeneratePower/Hydro.html#ANN>. Accessed June 5, 2005.
- 241 According to an Environment New Service report, at the URL below, the world’s first wave power plant is planned for a location five kilometres off Portugal’s north coast.
 1. <http://www.ens-newswire.com/ens/may2005/2005-05-24-04.asp>. Accessed June 5, 2005.
- 242 See *Wind Report 2004*, E.ON Netz GMBH, Bayreuth, Germany, available at the first URL below. A guide to this document is available at the second URL below.
 1. http://www.nowhinashwindfarm.co.uk/EON_Netz_Windreport_e_eng.pdf. Accessed June 5, 2005.
 2. <http://www.nowhinashwindfarm.co.uk/EON-Netz.Wind.report.guide.doc>. Accessed June 5, 2005.
- 243 Islam M, Fartaj A, Ting D S-K, Current utilization and future prospects of emerging renewable energy applications in Canada. *Renewable and Sustainable Energy Reviews*, 8, 493-519, 2004.
- 244 See the presentation by André Filion at the URL below.
 1. <http://www.pollutionprobe.org/whatwedo/GPW/montreal/presentations/filion.pdf>. Accessed June 5, 2005.
- 245 A recent review by the European Commission Joint Research Centre of production of electricity in Europe from renewable resources was similarly optimistic about the potential for photovoltaic systems: “Photovoltaics is right now on the brink of moving from a manufacture-type production to a fully fledged industry. ... Already, PV offers cost competitive solutions not only for remote locations but also for peak load electricity, e.g., California.” The review also concludes in respect to wind that “The technological advances during the last decade have already made wind energy cost competitive with conventional energy sources in regions with good wind resources.” (See Jäger-Waldau A, Ossenbrink H, Progress of electricity from biomass, wind and photovoltaics in the European Union. *Renewable & Sustainable Energy Reviews*, 8, 157-182, 2004.)
- 246 Growth in electricity use is presently driven mostly by air conditioning requirements, which could intensify with climate change. There are alternatives, including the use of permanently cold deep lake water. (See Gilbert R, Mason G, *Cooling Buildings in Downtown Toronto*. Canadian Urban Institute, Toronto, 1993.) ‘Deep lake water cooling’ is now being implemented in Toronto by Enwave Corp., which provides current information at the URL below.
 1. <http://www.enwave.com/enwave/dlwc/>. Accessed June 5, 2005.
- 247 Box 29 contains the opening words of Gilbert R, Sustainable Transportation. In Volume 5 of Munn E (ed.), *Encyclopedia of Global Environmental Change*. New York: Wiley, 2001.
- 248 The quotation is from Royal Commission on Aboriginal Peoples, *For Seven Generations*. Vol. 2. Ottawa: Ontario: Queen’s Printer, (1997), available at the URL below.
 1. http://www.ainc-inac.gc.ca/ch/rcap/sg/sh13_e.html. Accessed June 5, 2005.
- 249 Jacobs J, *Dark Age Ahead*. New York: Random House, 2004.
- 250 Diamond J, *Collapse: how societies choose to fail or succeed*. New York: Viking, 2005.
- 251 An interesting perspective on the importance of looking ahead was provided in a recent study of stated preference for commuting mode in relation to a disposition to be concerned about social issues or about future consequences of current activities. The latter disposition,

as assessed using a standard questionnaire, was found to be more strongly related to preference for commuting other than by car. (See Joireman JA, van Lange PAM, van Vugt M, Who cares about the environmental impact of cars? Those with an eye towards the future. *Environment and Behavior* 36, 187-206, 2005.)

- 252 Box 30 is based on person-kilometre data from the *Transportation Tomorrow Survey*, a five-yearly origin-destination survey conducted of residents in the Toronto region. Information about the survey is available at the URL below. The data in Box 30 are based on the 4.8 million residents of what in 2001 was the City of Toronto and the Regions of Durham, Halton, Peel, and York.
1. <http://www.jpint.utoronto.ca/dmg/tts.html>. Accessed June 5, 2005.
- 253 Box 31 is from Gilbert R, Nadeau N, *On decoupling economic growth from transport activity*. Paper presented at the May 2003 TRB workshop on Transport and Economic Development.
- 254 For example, one report concluded that more than half of the economic growth of then West Germany during the period 1950-1990 could be attributed to growth in transport activity. Of this contribution, only a small part lay in the direct contribution of transport activity; most came from transport's facilitation of other activities. (Baum H, Kurte J, Paper presented at ECMT Round Table 119, *Transport and Economic Development*. Paris, France: European Conference of Minister of Transport, February 2001.)
- 255 See, for example Vickerman R, Paper presented at ECMT Round Table 119, *Transport and Economic Development*. Paris, France: European Conference of Minister of Transport, February 2001
- 256 See Note 135 for a discussion and source on trading oil in euros.
- 257 Some analysts have noted that unless a sustainable energy source with limited potential is found, restraints on economic growth are inevitable. See, for example, Voorspools K, Sustainability of the future: rethinking the fundamentals of energy research. *Renewable & Sustainable Energy Reviews*, 8, 599-608, 2004.
- 258 A useful current review of the complex matter of transport elasticities is found in the *Online TDM Encyclopedia* of the Victoria Transport Policy Institute, available at the URL below.
1. <http://www.vtppi.org/tm/tm11.htm>. Accessed June 5, 2005.
- 259 According to the U.S. Energy Information Administration, between 1983 and 2002, gasoline prices rose at the rate of 0.9%/year; sales rose at the rate of 1.3%/year. Between January 2003 and January 2005, prices rose at the rate of 9.5%/year, but sales still rose at 1.0%/year. (See the data sheets at the first and second URLs below.) However, informal reports suggest that rising fuel prices are driving customers away from larger sport utility vehicles. (See Hakim D, Gas prices and poor sales push down Ford's profit. *New York Times*, April 21, 2005; McKenna B, Are, Ford, GM skidding out of control? *Globe & Mail*, April 12, 2005.) Meanwhile, over the last four years in the U.S. there has been a 56% per cent increase in sales of diesel passenger vehicles. (See Diesel sales rise, but they pale in comparison with Europe's appetite. *National Post*, April 8, 2005.) In 2004, they still comprised less than 3% of personal vehicle sales in the U.S. A recent survey suggested that two thirds of Americans agree it would be patriotic to buy a fuel-efficient vehicle (see *American Views on Fuel-Efficient Automobiles Efficient Automobiles and a Federal 40 MPG Standard*, Opinion Research Cor-

poration for the Civil Society Institute, March 17, 2005, at the third URL below.

1. http://www.eia.doe.gov/pub/oil_gas/petroleum/data_publications/petroleum_marketing_monthly/current/pdf/pmmtab7.pdf. Accessed June 5, 2005.

2. http://www.eia.doe.gov/emeu/mer/pdf/pages/sec9_6.pdf. Accessed June 5, 2005.

3. http://www.40mpg.org/pdfs/031705_40mpg_survey_report.pdf. Accessed June 5, 2005.

- 260 Box 32 was part of a presentation by Lee Schipper, then with the International Energy Agency, to a to a workshop on *Fuel Taxation* held by Transport Canada in Ottawa in March 1999.
- 261 For further discussion of path dependence, see Pierson P, Increasing Returns, Path Dependence and the Study of Politics, *American Political Science Review*, 94, 251-267, 2000. See also, North D, *Institutions, Institutional Change, and Economic Performance*. Cambridge, UK: Cambridge University Press. 1990.
- 262 See, for example, the paper by Hesse and Rodrigue detailed in Note 130.
- 263 This conclusion is based on data in Tables 1-32 and 1-45 of *National Transportation Statistics*, U.S. Department of Transportation, 2002, detailed in Note 26, which indicate that between 1990 and 1999 average truck trip length increased by 17% and the number of truck trips increased by 18%.
- 264 See Ubbels B, Rodenburg C, Nijkamp P, A multi-layer scenario analysis for sustainable international transport. *Transportation Planning and Technology*, 26, 69-103, 2003.
- 265 This advice was prompted by that given in Illum K, *Oil-based Technology and Economy: Prospects for the Future*, Danish Board of Technology and the Society of Danish Engineers, May 2004, available at the URL below.
1. http://www.tekno.dk/pdf/projekter/p04_Oil-based_Technology_and_Economy.pdf. Accessed June 5, 2005.
- 266 It might be noted in passing that moves to prepare for an oil-constrained future may well be consistent with creating a favourable business climate. According to the Economist Intelligence Unit, Denmark—a front-runner in such moves—has replaced Canada as the best place in the world to do business. (See: Canada drops to No. 2. *Globe & Mail*, March 29, 2005.)
- 267 An example of this ‘self-correcting’ approach is the article by Claudia Cattaneo detailed in Note 135.
- 268 These statements are based in part on a report on a report by investment bank Credit Suisse First Boston (Oster S, Big oil companies slow new exploration, OPEC to dominate – report. *Dow Jones Newswires*, January 17, 2005).
- 269 See Fialka JJ, Ball J, High prices bring together strange ideological bedfellows: Security experts urge policies to curb fuel use, a cause dear to environmentalists. *Globe & Mail*, March 28, 2005.
- 270 The importance of freight movement by consumers should not be overlooked. According the box on Page 6-18 of *Mobility 2001: World Mobility at the end of the 20th Century and its Sustainability* (World Business Council on Sustainable Development WBCSD, Geneva, Switzerland, available at the URL below), “the amount of fuel used by consumers in going to the store to pick up the groceries is five times as great as the fuel consumed by trucks and trains to get the groceries to the store”. I.e., in the analysed example, breakfast cereal, a rea-

sonably allocated share of shopping trips accounted for 83% of the field-to-table transport energy use. A different kind of analysis, concerning the whole UK average weekly food basket, estimated total externalities from transport and concluded that shopping trips comprised 32% of the domestic transport total and other road transport (e.g., trucking of goods to stores) accounted for the remainder. (See Pretty JN, Ball AS, Lang T, Morrison JLL, Farm costs and food miles: An assessment of the full cost of the UK weekly food basket. *Food Policy*, 30, 1-19, 2005.)

1. http://www.wbcsd.org/DocRoot/uu8taBpoTDXkvBiJHuaU/english_full_report.pdf, Accessed June 5, 2005.

- 271 See the sources detailed in Note 169 and associated text.
- 272 For Canada's options for renewable electricity generation, see the source detailed in Note 243.
- 273 Electricity generation and distribution in Canada (although not Mexico) are fully subject to NAFTA. The greater control arises because most provincial electrical utilities are publicly owned monopolies.
- 274 See Wack P, Scenarios: Uncharted waters ahead. *Harvard Business Review*, 63(5), 73-89, 1985.
- 275 See Burt G, van der Heidjen K, First Steps: towards purposeful activities in scenario thinking and future studies. *Futures*, 35, 1011-1026, 2003.
- 276 See Wiederkehr P, Gilbert R, Crist, P, Caïd N, Environmentally Sustainable Transport: the EST concept, goal, and strategy – The OECD's EST Project. *European Journal of Transport Infrastructure and Research*. 4(3), 11-25, 2004.
- 277 See Shiftan Y, Kaplan S, Hakkert S, Scenario building as a tool for planning a sustainable transportation system. *Transportation Research Part D*, 8, 323-342, 2003.
- 278 See Gertler M, Wolfe DA, Local social knowledge management: Community actors, institutions, and multilevel governance in regional foresight exercises. *Futures*, 36, 45-65, 2004.
- 279 See Canada Transportation Act Review Panel. *Vision and Balance: Canada Transportation Act Review*. Ottawa: Public Works and Government Services Canada, 2001.
- 280 See the National Round Table's Web site at the URL below.
1. http://www.nrtee-trnee.ca/eng/index_e.htm. Accessed June 5, 2005.