Preface

Transport Revolutions was begun during the summer of 2006, from two apartments on the south shore of Vancouver's Burrard Inlet, which provides oceangoing vessels with access to Canada's busiest port complex. The wealth of transport activity visible from our buildings inspired reflections on what has enabled human mobility to attain its current performance and what the future may hold.

The rooftop patio of the Gastown building that houses Richard Gilbert's rental apartment—his temporary home away from Toronto—provides a panoramic view of Vancouver's major container ship berths, where many thousands of containers from Asia are unloaded each week. Across the water, on the north shore of Burrard Inlet, raw materials are loaded on to bulk carriers for shipment to Asia. Separating the container quays from Gastown are the marshalling yards of the Canadian Pacific Railway, among the world's oldest and largest freight carriers. Trains several kilometres in length are assembled here to carry containers and other cargo to destinations across Canada and the United States.

At the west edge of the rail yard lies the West Coast Express terminal, where diesel-fuelled, double-decked commuter trains arrive from Vancouver's eastern suburbs on weekday mornings and depart in the afternoons. Between the rail tracks and the quays is a highway mostly used by lorries (trucks) moving things to and from the container ships. At the side of this highway is a large parking area used mainly by tourist coaches (buses), and another parking area used by a car rental company.

A smaller dock just west of the container-ship piers is used by tugboats that move the huge freighters in and out of the harbour. Next to the tugboat dock is a heliport where frequent flights carry Vancouver's business and political elite a hundred kilometres southwest across the Georgia Straight to Victoria, a much smaller city that is the province of British Columbia's capital. West of the heliport is the Vancouver terminus of the Seabus, a ferry that carries an average of some 15,000 passengers a day between Vancouver and North Vancouver, three kilometres across the harbour.

Where Gastown meets Vancouver's central business district, is Canada Place, visible from both authors' apartments. This is a large and growing convention centre, and office and hotel complex. It is also a cruise ship terminal. Berthing at the terminal, often three at a time, are the floating resorts that carry a million people each year on weeklong trips to view Alaska's glaciers. More noticeable from

Anthony Perl's Coal Harbour apartment is the steady stream of float planes arriving from and departing to Vancouver Island, Whistler and communities in the Gulf Islands. Both buildings are beneath the flight path of the 20 or so large jet aircraft that leave for Europe each day from Vancouver International Airport, 25 kilometres to the south west. Farther away but visible are aircraft of many sizes arriving from and en route to numerous places in the Americas and Asia.

What these diverse transport modes have in common is their use of one form or another of processed crude oil: the bunker oil used in ships, petrol (gasoline), diesel fuel, jet kerosene and others. Oil products fuel more than 95 percent of the world's transport. Without a steady flow of this energy source, all the motorized mobility visible in, around and above Burrard Inlet would come to a halt.

On the city side of the Gastown and Coal Harbour buildings that provide such extraordinary views of Burrard Inlet lies a local transport panorama dominated by cars and buses. It is a familiar urban traffic scene except in one respect. Most of the buses in sight are trolley buses, which have electric motors powered through overhead wires rather than the internal combustion engines that propel the world's much more numerous fleet of diesel-fuelled buses. The trolley buses move almost silently through Vancouver's streets, responsible for essentially no pollution in the city and little elsewhere because most of Vancouver's electricity is generated from falling water.

Many of these trolley buses are old, in service for 25 years or more, and for the most part rely on technology developed in the century before last. Nevertheless, they are popular, and TransLink, the regional transport authority, is upgrading the fleet with 228 state-of-the-art trolley buses purchased from a Winnipeg manufacturer and powered by German propulsion technology.

The trolley buses are popular because they are quiet and odourless and thus relatively inconspicuous, fitting well into the urban fabric. They could well become popular for another reason: they do not rely on oil. As world oil production peaks, supply fails to keep up with potential demand, and prices rise dramatically as a consequence, use of oil products as transport fuels could become prohibitively expensive.

Similarly popular but less noticeable in the city centre – because there it is below ground – is Vancouver's Skytrain, a 33-station electrified light-rail system running on guideways that are mostly above ground, sometimes at ground level, and sometimes below. The Skytrain system provides a substantial part of the Vancouver region with rail capacity approaching that of the more familiar heavy-rail systems known in the UK as the 'Tube' or 'Underground', in North America as 'subways', and elsewhere often as 'metros'. Skytrains are fully automated: no operator is required. Thus, they could serve as technical bridge to future automated systems in which passengers can direct small vehicles on guideways to particular destinations.

The popular alternatives provided by Vancouver's trolley bus fleet and Skytrain system beg questions as to the roles electric traction could play in maintaining the mobility of a world challenged by declining oil production. We make a case in this book that electric vehicles are the most important viable alternative to vehicles moved by internal combustion engines, and that they could quite quickly begin to replace oil-fuelled mobility on land. Their power could come mostly from overhead wires or rails, which can deliver renewable energy in a remarkably efficient manner. With some loss of efficiency, the power could also come from batteries. With much less efficiency, the power could come from fuel cells (which we do not find promising).

What is now a nearly invisible feature of the world's transport could become the dominant form, much as early mammals, scurrying inconspicuously at the feet of dinosaurs, adapted better to imperatives of cosmogeology and climate some 65 million years ago.

This book begins the exploration of a future in which mostly renewably produced electricity will increasingly replace oil as a transport fuel. In the course of this change, there will likely be several transport revolutions, transforming the movement of people and freight and the organization and use of the various transport modes.

Today's transport systems are little different from those of 30 years ago except in the amount of transport activity they support, which has increased by about a factor of three. Tomorrow's systems, those of 30 or more years hence, promise to be radically different, and support substantially different patterns of trade and social activity. In the following pages, we set out to explain why and how these changes will occur, and what they might imply for the human condition.

Such an investigation would have been much more arduous without the support we received from key people and organizations. Canada's Auto 21 Network of Centres of Excellence funded part of our collaboration through grants in its Societal Issues theme area for the project 'Policy Options for Alternative Automotive Futures'. Simon Fraser University supported this work through a President's Research Grant and Dean's Research Grants. We benefitted from research assistance provided by Ruby Arico, Graham Senft, Liu Xiaofei, and Michaela Rollingson. Many friends and colleagues provided valuable feedback on early drafts of this manuscript. Al Cormier, Susan Dexter, and Neal Irwin read drafts of all the chapters and had much influence on the book's final form and content. John Adams, David Gurin, Brendon Hemily, Tony Hiss, Catherine O'Brien, Bob Oliver, Judith Patterson and Linda Sheppard each commented on a substantial part of the emerging book and influenced it greatly. Emily Gilbert made numerous invaluable contributions to the identification of appropriate sources. Errors, omissions and analytical weaknesses in this book remain our full responsibility. There would have been many more of them without this input, for which we are truly grateful.

The forbearance our spouses, Rosalind Gilbert and Andrea Banks, deserves special recognition, reflected in the book's dedication. Our transcontinental collaboration consumed much of the time we would have otherwise spent with them during 2006 and 2007.

Richard Gilbert
Anthony Perl
Toronto and Vancouver
July 2007

Introduction: Transport Revolutions Ahead

WHAT IS IN THIS BOOK

This book examines the kinds of change that motorized transport around the world could undergo during the next few decades. Today, 95 per cent of this transport is fuelled by products of petroleum oil, chiefly petrol (gasoline), diesel fuel and jet kerosene.[1] We believe world oil production will peak in about 2012 and the amount available for use will then decline progressively. Meanwhile, the amount of oil that people would prefer to use will continue to increase, chiefly to fuel growing motorized movement of people and freight. The shortfall between potential consumption and actual production will cause petroleum prices to rise, perhaps steeply.

The high prices of oil could cause at least four kinds of transport revolution:

- Now, almost all transport is propelled by internal combustion engines. In the future, transport will be propelled increasingly by electric motors, using electricity increasingly generated from renewable resources.
- Now, almost all land transport is by vehicles that carry their fuel on board: petrol (gasoline) or diesel fuel. In the future, much land transport will be in electric vehicles that are grid-connected, i.e., they are powered while in motion, from wire or rails or in other ways.
- Now, almost all marine transport is propelled by diesel engines. Their use will continue but with assistance from wind via sails and kites.
- Now, air travel and air freight movement are the fastest growing transport activities. Soon, they will begin to decline because there will be no adequate substitute for increasingly expensive aviation fuels based on petroleum oil. Air travel and air freight movement will continue, but at lower intensities and mostly in large, more fuel-efficient aircraft flying a limited number of well-patronized routes, also with some use of partially solar-powered airships (dirigibles).

Four other factors could support and shape these revolutions:

- One is concern about pollution in cities, today caused mainly by the burning of petroleum-derived fuels in vehicles. Electric vehicles produce no such pollution at the vehicle.
- The second is concern about how human activity, particularly transport, may be contributing to climate change. Vehicles using electric motors can be readily fuelled from renewable resources that make no such contribution.
- The third is concern to achieve sustainability, so that succeeding generations can have a reasonable measure of well being. Sustainability requires reliance on renewable resources that can be as available in the future as they are today. Oil is not a renewable resource, but electricity can be.
- The fourth factor is avoidance of international conflict over energy resources, which will become more intense as oil production declines unless strong steps are taken to reduce oil consumption, particularly for transport.

The four revolutions we will explore in this book may not be inevitable, at least not within the next few decades. Enough oil ***could*** be found to maintain incremental growth in today's forms of transport activity. Petroleum-based transport fuels ***could*** be replaced by a to-be-developed liquid fuel that can be renewably produced in sufficient quantities. In our view, neither is likely to happen. After about 2012, as we will explain in Chapter 3, the world will enter an era of **oil depletion** characterized by progressively declining oil production. As we will explain in the same chapter, biofuels, liquids from coal and other products will nowhere near make up for the decline.

A more likely impediment to these revolutions will be lack of timely preparation. High oil prices will cause change, but the change will be destructive if it is not anticipated. In the worst scenario, car-dependent suburban residents who can no longer afford to refuel their cars, and have no alternative means to travel to work or buy essential goods, will have to abandon their homes or live at a subsistence level on what they can produce from their land. If a region dependent on food imports by lorry (truck) can no longer afford the transport costs, and there is no alternative means of moving food, residents will have to rely on what can be produced in the region, which may be too little for the numbers of people who live there.

Economic and social collapse is a real prospect if our oil-dependent societies do not prepare and implement workable plans to accommodate oil depletion. Then, there will be another kind of transport revolution, resulting in very much less motorized transport activity than humans now enjoy. This will be a transport revolution to avoid.

The four transport revolutions noted above could allow humanity to continue with at least the comfort and convenience of present arrangements and quite possibly more. How people and goods move will be different, but they will still move, with all the benefits of such movement. Moreover, there will fewer of the costs we accept today as being the price of progress such as transport-related poor air quality.

In Chapters 5 and 6, we discuss how transport-related preparations for oil depletion could unfold, with a focus on the US and China. These are respectively the most challenging among richer and poorer countries. We propose a process for initiating the required transport revolutions and offer some suggestions as to how matters might transpire during the first stage of these revolutions.

Four chapters prepare the ground for Chapters 5 and 6. Chapter 1 sets out what we mean by a transport revolution and looks back at five earlier examples, highlighting several of their features to gain perspectives on what transport revolutions bring about.

Chapter 2 reviews transport as it exists today worldwide, including the movement of both people and freight. Much more information is publicly available on the movement of people and we spend more time discussing this matter. However, we note that in many respects the movement of freight is as important and deserves more consideration than we and most others have been able to give it. For both people and freight we discuss local movement and movement among cities, countries and continents, considering differences between richer and poorer places. We look at recent trends and current projections, and discuss some of the causes of the transport activity. Almost all of our discussion concerns motorized transport but we do touch on bicycling and walking.

Chapter 3 focuses on transport and energy. We begin by explaining why we believe oil production will reach a peak within a few years and then decline progressively. Next we consider alternatives to oil as a transport fuel, focussing on electricity, which we believe to be the most viable alternative. Different kinds of electric vehicle and delivery system are assessed, and we conclude that grid-connected systems offer the most promise in an era of energy constraints. Finally, we consider how enough electricity might be generated to support widespread replacement of internal combustion engines by electric motors.

In Chapter 4, we discuss transport's adverse impacts, beginning with consideration of the global impacts. Currently, the most newsworthy potential impact is climate change, but we also consider other global impacts including stratospheric ozone depletion and dispersion of persistent organic pollutants. We suggest that oil depletion may be of more immediate consequence to human welfare than climate change but note that the issues and their resolution could be complementary. Then we move on to local and regional impacts, including air pollution and noise. Finally, we discuss what might loosely be identified as the adverse social and economic impacts of transport, the most salient of which are the outcomes of transport crashes and collisions. We note in several places in Chapter 5 that many of the impacts of transport would be reduced were electric motors to replace internal combustion engines as the prime means of traction.

Chapter 5 is the core of the book. There we look ahead to 2025 and show how for the US and China high levels of transport activity can be maintained while substantially reducing oil use. The overall framework for Chapter 5 is the amount of oil we believe will be available in 2025, based on the analysis in Chapter 3. This will be about 17 percent below what is produced in 2007. We expect that the US, as the example of a richer country, will achieve a greater reduction, in the order of 40 percent. China, as the example of a poorer country, will increase its oil consumption from the 2007 level, but by much less than current trends suggest. Moreover, by 2025, after reaching a peak in about 2020, China's consumption will be falling in 2025 with further declines to come.

For both the US and China, and for the movement of both people and freight, we set out mode by mode how transport activity could change between 2007 and

Chapter 1: Learning from Past Transport Revolutions

OVERVIEW

There have been two kinds of change in human mobility since hominids began exploring the African savannah: incremental change and revolutionary change. For much of history, people made incremental improvements to their inherited technology and practices for moving about. Tinkering with wheels, sails and engines produced real transport advances, but these gradual changes do not provide understanding of what makes a transport revolution occur and where it can lead. This chapter focuses on revolutionary changes: the more dramatic instances of rapid shifts from prevailing to new mobility patterns. These sudden changes were disruptive. They broke patterns of how people relied on technology for enabling mobility and they quickly changed expectations of what the norm in trade and travel was. These revolutions thus show how transport alternatives can reshape society.

We discuss earlier revolutionary changes in this chapter to help readers of this book think about the revolutionary changes in transport that we expect will occur during the early part of the 21st century. With the possible exceptions of riding a new high-speed train in France or receiving confirmation that their first overnight express package arrived, few readers will have personally experienced a transport revolution at around the time it was launched. Our five vignettes of past transport revolutions should help evoke those dynamics of change that, sooner or later, will become a lived experience for those reading this book.

What do we mean by a revolutionary change in transport? We need a definition that provides a clear, measurable distinction between an incremental change and a revolutionary change. Here is our proposal: **A transport revolution is a substantial change in a society's transport activity—moving people or freight, or both—that occurs in less than 25 years**. By 'substantial change' we mean one or both of two things. Either something that was happening before increases or decreases dramatically, say by 50 percent; or a new means of transport becomes prevalent to the extent that it becomes a part of the lives of 10 percent or more of the society's population. The two key features of our definition are these: First, there is a change in how people or freight move; the mere availability of a new technology does not constitute a revolution. Second, the change occurs relatively quickly; by our definition, horseback riding would not qualify as revolutionary because its extensive adoption likely took hundreds or even thousands of years.

A new technology such as the unicycle or the Segway is not revolutionary until it results in a significant shift in the way people travel. This could take the form of a large number of new trips using the new mode or a shift to the new mode from an existing mode such as bicycling or walking. Even ‘big’ technological advances such as the Boeing 747 or the Airbus 380 aircraft do not count as revolutionary unless they result in large, rapid changes in transport activity.

Our concept of a transport revolution is thus behavioural, and differs from the usual way of characterizing transport revolutions in terms of availability of transport modes or technologies. An example of a more conventional characterization is in Table 1.1

Table 1.1 *Transport revolutions in human history*[1]

Era	Approximate Date	Ways of moving people and goods
Palaeolithic	From ca. 700,000 BP	First migrations of hominids from Africa
	From ca. 100,000 BP	First migrations of modern humans from Africa
	From ca. 60,000 BP	First migrations by sea to Australasia
Agrarian	From ca. 4000 BCE	Animal-powered transport
	From ca. 3500 BCE	Wheeled transport
	From ca. 1500 BCE	Long-distance ships in Polynesia
	1st millennium BCE	State-built roads and canals
Modern	1st millennium CE	Improvements in shipbuilding, navigation
	From early 19th century	Railways and steamships
	From late 19th century	Internal combustion engines
	From early 20th century	Air travel
	From mid 20th century	Space travel

BP = before the present. BCE = before the common era (i.e. before Year 1 in the Christian dating system). CE = common era

In this chapter, we present five examples of transport revolutions that expose the common and uncommon elements of major mobility change. Through these examples we identify some of the factors and forces that precipitate revolutionary rather than evolutionary mobility change. Our examples are meant to be illustrative rather than exhaustive of the range of factors associated with a significant reconfiguration of transport technology and socio-economic organization.

We begin with a transport revolution motivated by the belief that Britain’s industrial revolution was generating more goods movement than existing roads and canals could accommodate. Britain’s emerging railway entrepreneurs believed that the steam locomotive offered a technology that could deliver a faster and cheaper mobility option and thus generate considerable profit while meeting future demand. **A belief that existing transport is inadequate and that major improvements are**

required can thus be a key factor spurring the investment and risk-taking required to launch revolutionary new mobility.

A different kind of transport revolution occurred during the Second World War, when the United States suddenly restricted the production and use of automobiles, and the expansion of its road network, in order to accelerate military mobilization. **This revolution highlights the role that governmental authority can play in reorganizing mobility when national security is perceived to be at stake**. In this case, the reorganization was achieved through the imposition of gasoline rationing and industrial planning, used as tools to radically redesign the way people moved locally and between cities. By 1942, the private automobile had lost its place at the forefront of America's mobility growth. Inter-city trains and local public transport were filled as they had never been before and mostly have never been since. This transport revolution ended as suddenly as it began, with a quick downsizing of military production and a rush back to car production that set the stage for a great suburban expansion.

Between 1950 and 1975, the third transport revolution we describe involved a profound transformation in the way people travelled over long distances. The rapid replacement of ocean liners by aircraft as the main means of travelling across the Atlantic represented a revolution in the intercontinental movement of people. **A key element of this change was the adaptation of transport technology invented for military use**—jet aircraft—to yield dramatic performance improvements in an existing mode. This example also shows how a revolution can trigger the subsequent reinvention of an apparently obsolete transport mode: in this case the reincarnation of the ocean liner as a cruise ship.

Our fourth example concerns another approach to adaptation where the innovation in technology occurs under public-sector initiative with a civilian focus. The reinvention of the passenger train began with the introduction of high-speed rail in Japan in 1964 and in Europe by 1982. Limitations of existing train technology and enterprise structure prompted innovators to 'go back to the drawing board' and develop a new railway system that had little in common with its predecessors. The result was a major change in the way that people travelled between cities 300-800 kilometres apart. **This transport revolution reinforces the concept that mobility options can be reinvented after a period in which they experience decline in the face of competition**.

From 1980 onwards, the movement of cargo by aircraft underwent a transport revolution that rounds out our consideration of these upheavals. Before this revolution, air cargo was being moved almost entirely in the holds of passenger aircraft, with limited integration into ground transport networks. Entrepreneurs at Federal Express applied 'hub and spoke' routing to flights carrying only cargo, integrated these with door-to-door delivery, and launched a revolutionary expansion in freight movement. From being an exceptional and expensive proposition, next-day delivery times became commonplace. This transformation in air freight service levels made it possible to develop global logistics networks that could support production and distribution on an unprecedented scale. **It shows how organizational changes can be as important for a transport revolution as changes in technology.**

We chose to explore these five transport revolutions because they illustrate a range of dynamics that could be expected to occur in coming transport revolutions. In their impact, they have not necessarily been the most important revolutions.

Chapter 2: Transport Today

INTRODUCTION

This chapter describes transport today, touching on history, trends and causes. It deals with the movement of people and freight by land, water and air. **It sets the scene for the discussions in Chapters 5 and 6 as to where transport could or should be heading**.

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 were those to the Americas: from Asia in the millennia before history—across what is now the Bering Strait to as far south as Tierra del Fuego—and from Europe and Africa during the last millennium and perhaps before.

Societies across the world have progressed in military, economic and social matters—not always at the same time—to the extent they have mastered and improved upon 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 development have become increasingly tight.

Until the 19th century, travel everywhere was uncomfortable, dangerous, and enormously time-consuming. Freight movement posed even greater challenges. The barriers of distance were overcome where feasible by use of inland waterways, including canals, but mechanized rail transport made the real difference in accelerating the scope and volume of transport. 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 transport over water.

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. Transport's evolution since the

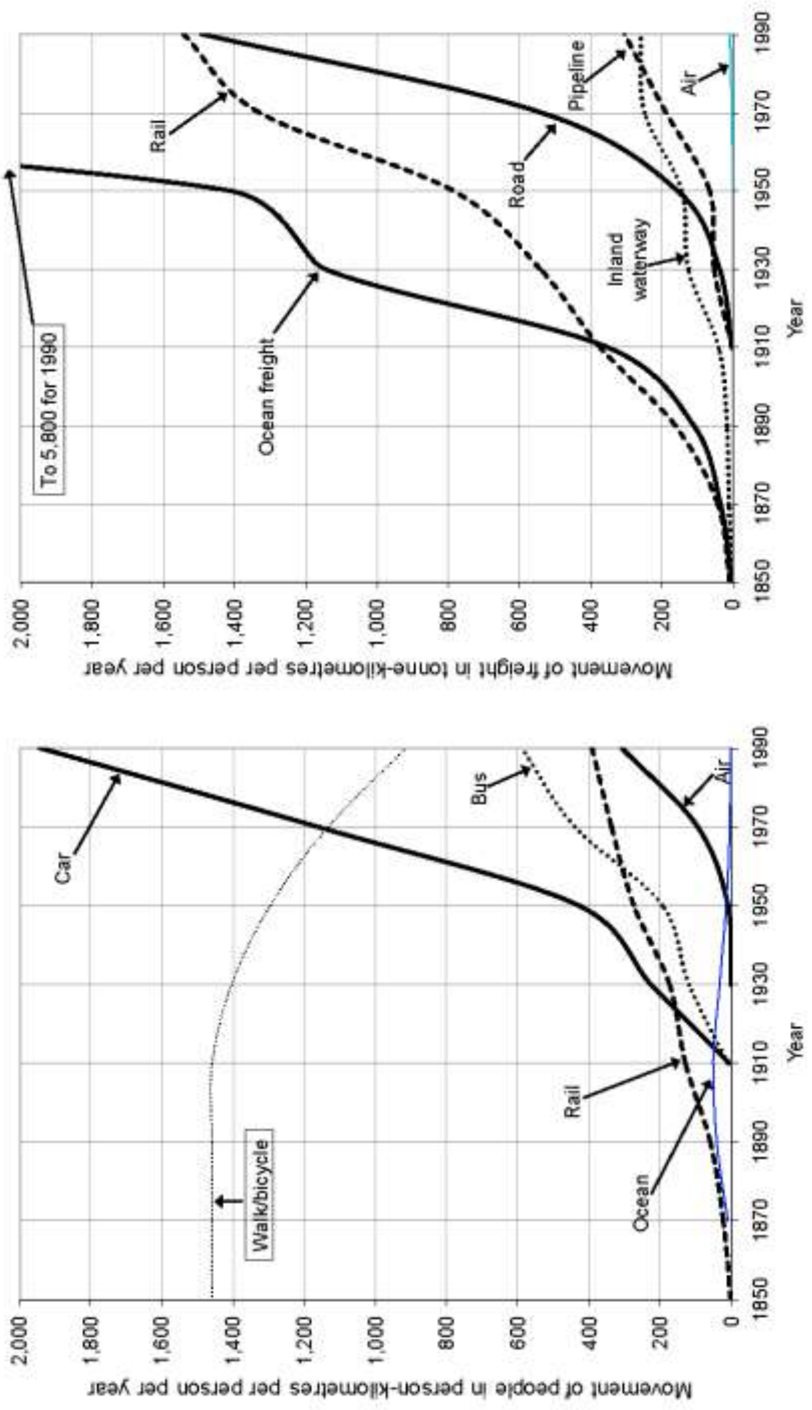

Figure 2.1 World-wide per-capita movement of people and freight, 1850-1990[1]

mid-19th century is shown in Figure 2.1. Developments since 1990 are summarized later in Figure 2.15.

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. Motorized transport has also facilitated some of the low points of recent human history including the Holocaust and the Soviet gulags.

The growth of personal road transport—chiefly cars (automobiles)—has been closely associated with two of the major phenomena of the twentieth century: growth in material well-being and expansion of democratic institutions. Ownership of a car—usually the most expensive of consumer purchases—has assumed in rich countries the status of a democratic right. As a token of passage into adulthood, qualifying to drive a car can be more important than qualifying to vote.[2] In Central and Eastern European countries, relaxation of prohibitions on car ownership often preceded enfranchisement,[3] and may have contributed to it.

The unusual case of Hong Kong shows that the desire for car ownership is not universal. There, according to a survey, only one in a hundred university students owns a car and less than in one in five would want one. The author of the survey report concluded, '… if public transport is generally perceived to be good and cheap, it can suppress demand for cars'.[4] Other factors are relevant in Hong Kong's case, including the high cost of car ownership and use, and the limited opportunities for driving.[5]

By 2007, world totals for the *motorized* movement of people and freight had grown to truly remarkable levels. Estimates of these, and the fuel used, are in Box 2.1. Most often, the totals are in *trillions*, i.e., millions of millions, numbers almost beyond comprehension. The present chapter provides a fine-grain analysis of this movement. How it is fuelled and its impacts are discussed respectively in Chapters 3 and 4.

The next section concerns the *local* movement of people, i.e., their everyday travel, to work places and other places by motorized and non-motorized means. Sometimes we make a loose distinction between higher-income and lower-income countries and urban regions. 'Higher-income'—also 'affluent'—refers to countries or regions that had a per-capita Gross Domestic Product (GDP) of more than about US$10,000 in 1995. Also, because of the way in which some data are available, we instead occasionally distinguish between members of the Organization for Economic Cooperation and Development (OECD),[7] which are mostly higher-income countries, and other countries.

There are major differences in local travel, not only between higher- and lower-income places, but also within the same country and even within the same urban region. We lay out some of the reasons for these differences.

The subsequent substantive section focuses on how people move over longer distances, within their countries and between countries. This mainly concerns people in richer countries. Poorer people engage in relatively little longer-distance travel. Air travel is a major focus of this section, and we spend some time describing a current major phenomenon in this industry: the rise of low-cost air carriers.

The final section, before a brief conclusion, presents data on freight movement, a much neglected topic for which there are relatively few data, especially about local

Chapter 3: Transport and Energy

INTRODUCTION

Products of petroleum oil fuel almost all of today's transport. A considerable part of the chapter concerns prospects for continued sufficient supply of oil to meet anticipated transport activity and the prospects for replacing oil as the main transport fuel. Our conclusion is that world oil production will begin to fall during the next decade and that electricity is the most likely replacement, with much of it eventually produced from renewable resources. We discuss electric vehicles, as well as vehicles that use oil products and other fuels. Finally, we consider how enough electricity might be produced to replace oil as the main transport fuel.

Today's widespread oil use is a recent phenomenon. Figure 3.1 shows that more than 50 percent of the oil ever used has been used since 1983 and more that 95 percent of the world's total oil consumption has occurred since the beginning of the Second World War. The cumulative total consumption of 1.036 trillion (10^{12}) barrels

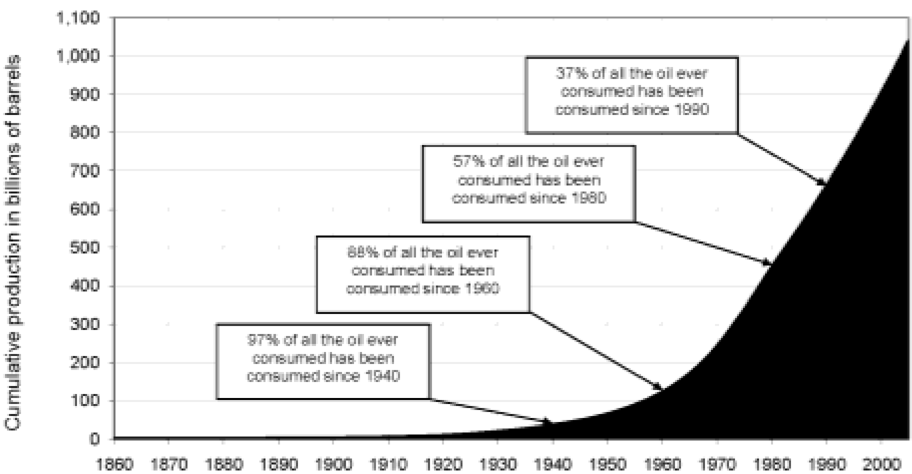

Figure 3.1 *World cumulative oil consumption, 1860-2005*[2]

To return to the main page of the *Transport Revolutions*' Web site, click here

appears to be approaching about half of the oil that could ever be extracted.[1] We believe this milestone, due in about 2012, will likely be associated with the beginning of a progressive decline in the amount that can be produced—and thus consumed—in any year, as we discuss below.

According to conventional economic notions, when an item is abundant its price is relatively low and when it becomes scarce its price rises. The higher price suppresses consumption to the level of availability of the item. Scarcity thus produces a new equilibrium of price and consumption. The higher price can also increase supply in the form of more expensive alternatives to the item. The alternatives become feasible to produce, and their price may decline because of the quantities produced.[3] In the case of oil, the alternative could be difficult-to-reach oil whose production was not profitable at the lower price. The alternative could also be another fuel such as ethanol that can be intrinsically more costly to produce than oil. Such additions to supply reset the equilibrium again, this time towards a lower price and more consumption, but perhaps not to such as low price as before and with consumption still below the initial level. **In this chapter we explore how much the price of oil and products could rise as oil production falls, and discuss what may be the most feasible alternative fuel: electricity.**

OIL AND ITS FUTURE

Production of transport fuels

Some 95 percent of the fuel used for transport is a liquid petroleum product made from crude oil.[4] Cars run mostly on petrol (gasoline), although increasingly in Europe they run on diesel fuel.[5] Diesel fuel is denser, less volatile and contains more usable energy per unit volume than petrol. Lorries (trucks) run mostly on diesel fuel, although smaller ones use petrol. Small boats use petrol. Large ships invariably use diesel fuel, or a dense, high-sulphur variant of diesel fuel known as bunker fuel. Non-electric locomotives mostly use diesel fuel, usually for generators that power electric motors that drive the wheels, but also, in smaller locomotives, for engines that drive wheels directly. A few locomotives still use coal, chiefly to give tourists a sense of rail travel in earlier times. Jet aircraft use a form of kerosene, which is similar to diesel fuel. Propeller aircraft use aviation petrol, also known as avgas. It is similar to what automobile petrol used to be like in that it contains a lead compound to reduce uncontrolled ignition of the fuel (‘knocking’).

The three main fuels—petrol, diesel fuel and aviation gasoline—correspond to the three main types of internal combustion engine (ICE) that today propel almost all transport. In two of these types of ICE, fuel ignites within a closed cylinder, expands and moves a piston whose action is converted into rotary motion. In one of these two types, which uses petrol as a fuel, ignition is achieved by a carefully timed electric spark. In the other type, ignition occurs when diesel fuel is subjected to high pressure by the returning piston. These two kinds of ICE thus operate through making use of series of contained explosions of their fuels.

The third type of ICE, the gas turbine engine, burns fuel continuously, producing a high-velocity flow of exhaust gases. In a jet engine, which is a form of gas turbine engine, this flow of gases provides the thrust that results in propulsion. As well, a turbine, propelled by the exhaust gases, compresses fuel and air for ignition and powers other equipment. In a turbofan engine, used in most non-military jet aircraft, a fan driven by the turbine acts like an enclosed propeller and provides additional thrust. For other applications of gas turbine engines, including in some cars and locomotives, energy is recovered mainly from the turbine rather than from the direct thrust of the exhaust gases. The turbine's mechanical energy can be used directly or after conversion via a generator to electrical energy.

The three types of fuel are derived from crude oil in oil refineries, in what has been described as 'one big fuming silo'.[6] The crude oil is boiled at the bottom and its fumes rise into the column. The temperature of the column declines with increasing height, and different products condense out according to temperature: asphalt at 600°C, followed by lubricating oils and greases (400°C), heating oil, diesel oil, and jet kerosene (200°C), naphtha (70°C), and propane and butane (20°C). Much blending with lighter oils and gases is carried out, both of the crude oil before it is boiled and of the products of distillation, notably naphtha, which is blended to form petrol (gasoline).

The refining process is moderately energy-intensive, consuming about 10 percent of the energy available in the materials produced. The remainder of the processes of extraction, conditioning, and transport of conventional crude oil from well to vehicle require a further 5 percent.[7] What is meant by 'conventional oil' is set out below.

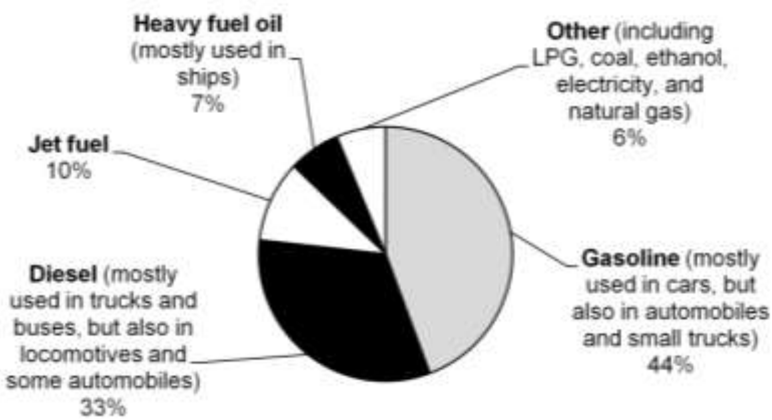

Figure 3.2 *World end-use consumption of transport fuels, 2003*[12]

World consumption of transport fuels

World consumption of transport fuels in 2004 was 2.03 billion (10^9) tonnes or 14.9 billion barrels.[8] In energy terms, it was 91.0 exajoules, i.e., 91.0 billion billion (10^{18}) joules.[9] Figure 3.2 shows the shares for each fuel of total end-use transport energy consumption in 2003. Worldwide, transport energy was almost evenly shared between petrol (gasoline), on the one hand, and denser fuels including diesel fuel and jet fuel, on the other hand. There were strong regional differences. For example, in Europe, where most new cars have diesel engines,[10] diesel and other denser fuels comprised 71 percent of use of transport fuels. In Japan they comprised 53 percent, and in the US, where diesel-fuelled cars are rare, they comprised only 43 percent.[11]

Chapter 4: Transport's Adverse Impacts

INTRODUCTION

This chapter discusses the adverse impacts of present motorized transport. These are mostly but by no means entirely the result of the use of internal combustion engines (ICEs) to propel today's vehicles. We could have included a chapter on transport's benefits, but they hardly need stating. We noted in Chapter 2 how effective transport gave advantage to particular peoples in history, and how motorized transport has facilitated and even stimulated just about everything now regarded as progress. What should be added is the suggestion that beyond a certain point the costs of increased mobility may outweigh the benefits:

> Near the end of the 20th century, the belief in the desirability of perpetual growth in mobility and transport has started to fade. In many countries, highway accessibility is so ubiquitous that transport cost has almost disappeared as a location factor for industry. In metropolitan areas, the myth that rising travel demand will ever be satisfied by more motorways has been shattered by reappearing congestion. People have realised that the car has not only brought freedom of movement but also air pollution, traffic noise and accidents. It has become obvious that in the face of finite fossil fuel resources and the need to reduce greenhouse gas emissions the use of petroleum cannot grow forever. There is now broad agreement that present trends in transport are not sustainable, and many conclude that fundamental changes in the technology, design, operation, and financing of transport systems are needed.[1]

Figure 4.1 provides an illustration of what may happen as the level of motorization increases. Benefits from growing mobility—in terms of greater access to people, goods, and services—grow more steeply at first. Congestion and the costs of managing it grow with increasing motorization, perhaps less steeply at first. Environmental and social costs grow in proportion to the level of motorization. Beyond a certain point—'A' in Figure 4.1—*net* benefits begin to decline. At a higher level of motorization—'B' in Figure 4.1—the costs of increasing mobility outweigh the benefits. A good question to ask is whether we have too much mobility when point B is reached. Or does the condition of what has been called 'hypermobility'[2] begin at point A, when net benefits begin to decline?

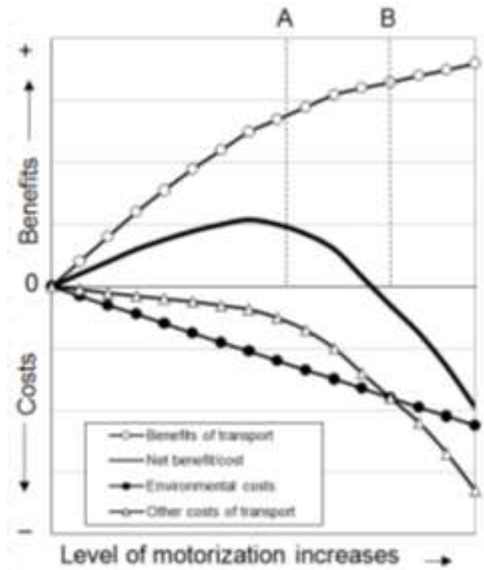

Figure 4.1 *Schematic illustration of mobility benefits and costs*[3]

Another approach has been to note that **access to goods, services and people has not kept pace with mobility**. Figure 5.2 suggests that people in what used to be West Germany had hardly more access to destinations in 1990 than they did in 1960, when there were much lower levels of mobility. This was chiefly because car ownership and use levels were much lower.

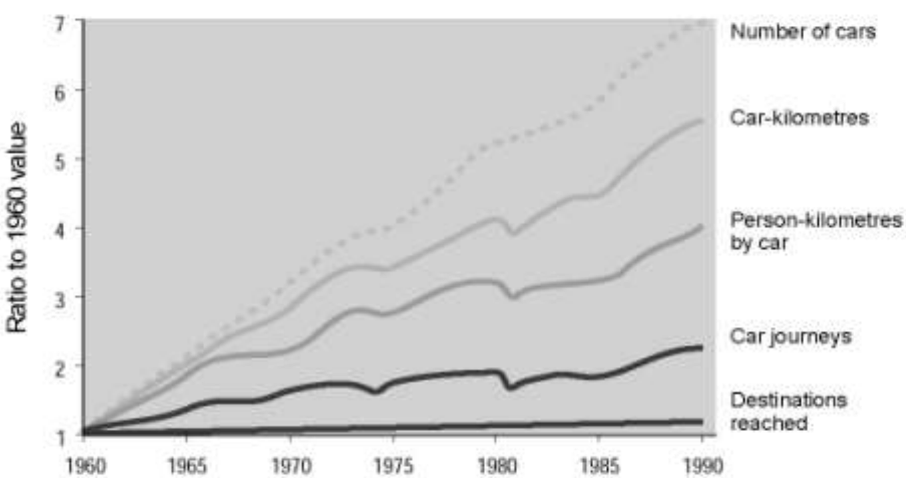

Figure 4.2 *Mobility and access in West Germany, 1960-1990*[4]

The main change was that in 1990 access was much more often achieved by car, whereas in 1960 it was achieved more by public transport, walking and cycling. Destinations were probably on average farther away in 1990 than in 1960.

This chapter begins by considering the global environmental impacts of transport, chiefly on climate change but also ozone depletion and the proliferation of persistent organic pollutants. The impacts on climate change are considered in relation to the possibility that oil production will reach a peak during the next decade, as discussed in Chapter 3. We next consider transport's local and regional environmental impacts. The focus is on atmospheric pollution and air quality, but impacts on land and water are also considered. Finally, there is some consideration of adverse social and economic impacts.

In parts of the world, some warming could be considered desirable.[9] Nevertheless, warming by even a few degrees could have numerous adverse effects. They include an increase in extreme weather events, changes in land and marine growing seasons and species composition, sea level rise and consequent flooding, changes in water availability, infrastructure damage and health effects from heat stress and changes in disease patterns.[10]

Box 4.1 *Cosmoclimatology*[8]

The prevailing account of ongoing climate change, particularly the rising average temperature of the Earth's surface, is that it is caused chiefly by anthropogenic (i.e., human-produced) emissions of radiatively active gases, usually known as greenhouse gases (GHGs). A coherent alternative account is that the warming can be attributed to a decline in the amount of cosmic radiation penetrating the Earth's atmosphere.

Cosmic rays are the result of stellar activity, notably the explosive 'deaths' of stars. They comprise charged subatomic particles, mostly protons. In air containing water vapour, these particles release electrons that initiate cloud formation, particularly over oceans at heights below about 3 kilometres. Such low-level clouds cool the Earth, offsetting some of the warming produced by the Earth's blanket of water vapour and other GHGs. Increases in the Sun's magnetic activity reduce the amount of cosmic radiation reaching the Earth, and vice versa. According to the alternative account of global warming, increased solar activity over the last century has reduced cosmic ray penetration, resulting in less low-level cloudiness and consequent less cooling.

Henrik Svensmark, the Danish physicist who proposed this account, claims that it can explain all the 0.6°C of global warming between 1900 and 2000. He allows that the increase in anthropogenic GHG emissions may also have had an impact, albeit minor. Svensmark argues that his theory accounts for many other features of climate change, including the 'snowball' and 'hothouse' Earth's of the distant past, the medieval warm period and subsequent low temperatures, and the current cooling of Antarctica (which is opposite from what might be expected if changes in atmospheric GHGs were the main cause of global warming).

Svensmark and co-author Nigel Calder note that, 'To correct apparent overestimates of the effects of carbon dioxide is not to recommend a careless bonfire of the fossil fuels that produce the gas … there are compelling reasons to economize in the use of fossil fuels that have nothing to do with climate: to minimize unhealthy smog, to conserve the planet's limited stocks of fuel, and to keep energy prices down for the benefit of poorer nations.' Svensmark and Calder use the term *cosmoclimatology* to embrace investigation of the effects of cosmic rays on the Earth's climate.

Chapter 5: The Next Transport Revolutions

SETTING THE SCENE FOR 2025

Almost everything in this book so far has concerned the past or the present. In this chapter we venture forward, mindful of the advice that 'prediction is very hard, especially about the future' (advice given perhaps independently by Neils Bohr, Danish atomic physicist, and then by Yogi Berra, US baseball player and team manager). In the spirit of this advice, what we present in this chapter about transport's future is more in the form of suggestions as to how transport *could* unfold than predictions as to how it *will* unfold.

We are sufficiently confident to predict that a particular energy future will impel revolutions in transport during the next few decades. The limit to growth in the world oil production will be reached during the next decade, possibly around 2012, for the reasons discussed in Chapter 3. We also predict that the shortfall in oil production in relation to potential consumption will cause oil prices to rise steeply and these price increases will trigger organizational and technical innovations that will spark transport revolutions. We are by no means certain that this sequence of events will occur but we believe they are more likely to occur than any of the alternatives. The alternatives include among others: no peak in world oil production; a peak that is not followed by steep price increases; and peak-induced price increases—more precisely, oil-depletion-induced price increase—that are not followed by transport revolutions.

In Chapter 1, we defined a transport revolution as a substantial change in a society's transport activity—moving people or freight, or both—that occurs in less than about 25 years. 'Substantial change' means one or both of the following: an ongoing transport activity increases or decreases dramatically, say by 50 percent, or a new means of transport becomes prevalent to the extent that it becomes a part of the lives of 10 percent or more of the society's population.

We see the possibility of two broadly divergent types of revolution. One type would involve accommodating *energy decline*, and chiefly comprise a winding down of much transport activity because the oil needed to fuel it will not be available and because there will be little in the way of alternative transport that is not dependent on oil. Such revolutions would likely not begin before the peak in oil production was reached. The other type would involve anticipating and implementing *energy redesign*, yielding a new configuration of transport technology and organization that replaces oil as the energy source powering most motorized mobility. This approach would most likely be launched *before* world oil production peaks.

We have little interest in the former approach to change, apart from noting a growing preoccupation with societal collapse.[1] Our focus will be on stressing the need to prepare for what we described in Chapter 4 as *oil depletion*. This refers to a decline in oil production after peak production. When one country experiences oil depletion—as dozens have, most noticeably the US from 1970 on—it can import oil from elsewhere. When world production can no longer grow, as we expect will happen during the next decade, a growing shortfall between production and potential consumption could result in very high oil prices, as we explained in Chapter 3. We do believe, however, that higher prices will provide a greater spur to action than the *prospect* of higher prices. Thus, although preparation in advance of the peak may be essential, much of what will come to be recognized as inter-related transport revolutions will not become evident for a decade or two.

Our interest is in figuring out how an anticipatory approach could prepare for as much of the redesign capacity as possible before oil price increases reach crisis proportions. We believe that such preparation is essential for enabling the continuation of humanity's gains in comfort, convenience, productivity and freedom from want. We don't think we can predict with any confidence how transport activity would actually unfold in the course of either type of impending revolution, whether managing decline or anticipating and implementing energy redesign. We do feel we can help the prospects for the latter approach by offering suggestions as to what might be done.

The purpose of this chapter is thus to show how a transition away from oil used for transport could be managed through anticipation. To do this we focus on two countries, the US and China. We chose these countries because they present the most challenging cases among what are now richer countries and poorer countries. The US is the most challenging case among richer countries because it engages in much more transport activity and uses much more oil for transport per capita than any other country, as was detailed in Chapters 2 and 3. China provides the most challenging case among poorer countries because it is larger and more populous than any other and because its transport is expanding and motorizing more quickly than any other, as also detailed in Chapters 2 and 3. These two countries are first and second among consumers of oil in the world, and first and third among importers of oil.[2] (China is behind Japan in oil imports, but is on a trajectory to pass Japan in about 2010.)

A reminder may be in order that China remains among the poorer countries in spite of her remarkable growth in industrial production and wealthy entrepreneurs. Although China's gross domestic product (GDP) is by some counts the second or third highest among the world's economies, after the US, her GDP *per capita* ranks halfway down the 200-plus list and is well under half of the world average.[3]

As well as being the most challenging cases—and the weightiest cases on account of their high levels of oil consumption—the US and China are important because they are the most influential countries in a whole range of socio-cultural and economic domains. In addition to their economic significance, they have importance as centres of the world's two most widely used languages, Mandarin and English.[4] The US in particular has a disproportionate cultural reach because of its dominance in film and other mass media. A US move away from oil could have extraordinary influence in many ways.

We will go into some detail about *what* could happen in the transport revolutions to come in the US and in China, but we will not provide detailed prescriptions as to *how* to redesign every aspect of mobility during these transport revolutions. Such designs would easily fill another book, and several more will likely be written about the methods of changing mobility arrangements in response to oil depletion. Many books are being and will be written about how transport activity should respond to the prospect of further climate change. All these books will have much in common with the present work and there will be much to learn from them. As we argued in Chapter 4, we believe oil depletion is the more urgent issue and should be given priority. We also believe that viewing transport futures from the perspective of oil depletion brings essential clarity to our current predicament and what has to be done about it.

This chapter's prelude to transport system redesign is built around two pairs of scenarios for 2025: scenarios for the movement of people and freight for each of the US and China. Each scenario is presented in terms of suggested targets for transport and energy use for each mode, set out in relation to what is happening in 2007. **We chose 2025 as the target year for several reasons:**

It is near enough to provide a meaningfully close target date that could motivate early action—as opposed to simply planning for action—by current government and corporate leaders. If we had chosen 2050, there could be a strong temptation to put off action until 2025 or later, or at least until the next generation of leaders will be in a position to deal with these challenges. For some people, 2025 may seem far in the future; but in relation to 2010, which may be the latest date to begin anticipatory redesign that can keep ahead of major oil price increases, 2025 is only as far in the future as 1995 is in the past.

This 15-18 year period is also a sufficient period within which to attain some significant results from redesigning transport systems. Some of the dramatic changes in transport activity described in Chapter 1 occurred over shorter periods. Moreover, 2025 will be a decade or so after we expect the occurrence of the world peak in production of petroleum liquids to become evident. (We suggested in Chapter 3 that the actual peak could be in 2012, but its attainment will not be apparent for a few years.)

If we had set the target year even five years later, in 2030, the required cuts in oil consumption would have been larger, and more likely to appear intimidating and engender defeatism.

The key factor in establishing our redesign scenarios is therefore the extent of the reductions in oil consumption that would be required by 2025. For this we look first to Figure 3.8 in Chapter 3, which suggested that world oil production—and consumption—in 2025 will be in the order of 26.3 billion barrels (bb). This is only 17 percent below the likely production in 2007 and it is actually 7 percent *above* production in 1990. However, **the most important difference is that anticipated oil production of 26.3 bb in 2025 would be 35 percent below the projected 'business-as-usual' consumption of 40.4 bb in 2025**. These production estimates and percentage changes are all set out in the bottom row of Table 5.1.

We should stress that world oil production and consumption in any year are essentially identical. What is produced is mostly used in the same year, and the amounts carried over from one year to another—in transit or in storage—vary little

Chapter 6: Leading the Way Forward

SAUDI ARABIA COULD BE THE TIPPING POINT

This closing chapter addresses above all the role of leadership in securing smooth transitions towards transport options that do not depend on oil. First, we recapitulate where things stand in respect to oil production and consumption. The broader picture was set out in Chapter 3. Here we add some details. They are in Figure 6.1, which shows recent world production and consumption, and data on production or consumption for particular parts of the world.

The upper left panel shows that world production of conventional oil and other petroleum liquids appears to be reaching a peak. We believe this is chiefly because of the increasing relevance of the kinds of geological constraints noted in Chapter 3. The inset in this panel shows recent increases in world oil prices, which we believe to be caused by the emerging mismatch between desired consumption and available production. (Figure 3.9 in Chapter 3 is a more readily viewable chart of recent oil prices.)

An alternative interpretation of the upper left panel in Figure 6.1 is that the causal relationship is the other way around: the declining rate of increase in world oil consumption is caused by the rising prices. These in turn could be caused by non-geological factors such as political instability and economic volatility including boom-bust resource cycles. In this interpretation, the growth in production has slowed to match desired consumption. Yet another view is that producers are restraining production to keep prices high. There may be some truth to each of these accounts. However, for the reasons given in Chapter 3, we believe that geological constraints are the immutable factor behind the declining rate of increase in production—and thus consumption—that will remain relevant once other production constraints are removed.

The pressures of consumption are exemplified in the upper right panel of Figure 6.1. This chart shows the extraordinary growth in oil use in China during the last five years—by 61 percent between early 2002 and early 2007—but with a gradually decreasing rate of growth over this period. Consumption by most other poorer countries has grown too, although usually by less. Oil use in India, for example, grew by 24 percent across the same period.[2]

Oil consumption in richer countries has been relatively stable, as shown in the bottom left panel of Figure 6.1. Over the five-year period until the first quarter of

2007, US consumption increased by eight percent, perhaps reaching a peak in 2006. Consumption in Europe fell by one percent, and consumption in Japan (not shown) fell by five percent. Figure 6.1 suggests that consumption in Europe may have reached a peak in 2004 (although not necessarily *the* peak in its consumption).

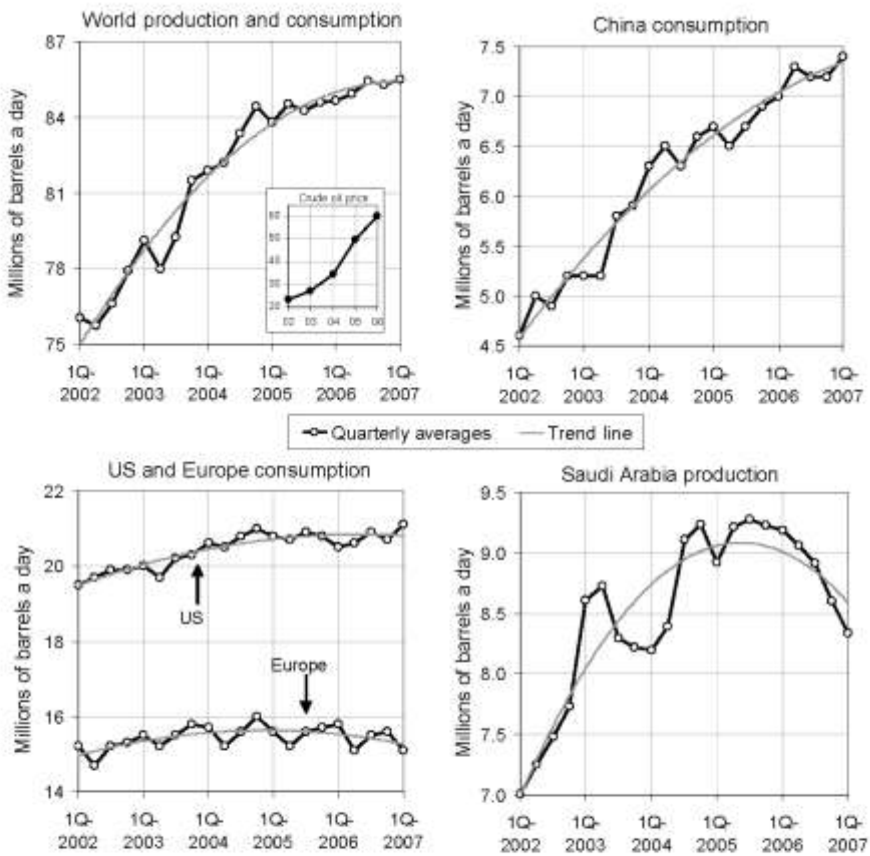

Figure 6.1 *Recent oil production and consumption, and price (insert)*[1]

A reasonable conclusion from the forgoing is that the growth in world production and consumption is moderating and that any tendency to increase consumption is coming from the US and from poorer countries, especially China.

The bottom right panel of Figure 6.1 shows that oil production by Saudi Arabia, the main producing country, may have reached a peak in 2005. This conclusion is made cautiously, not the least because from the perspective of 2004 the peak might have appeared to have been in 2003. The maximum in 2005 appears to be more robust, but a few more years of decline would be required for some confidence that production peaked in 2005. There have been other suggestions that Saudi Arabian production has peaked.[3] However, a case could also be made that Saudi Arabia is holding back production to sustain high oil prices. Too little information is available to know with any certainty one way or the other.

Actors in energy and financial markets often consider Saudi Arabia as the world's reserve producer that guarantees some measure of price stability for energy users, much as a central bank—such as the US Federal Reserve Bank and the Bank of England—is seen as a guarantor of the stability of a currency. Assessing the intentions of the Saudi Arabian government is much more challenging. For example, in January 2007—when world oil prices were around $50 a barrel, lower than at any time during 2006—this was written: 'Prices at $50 to $55 a barrel are just about right for the Saudis, according to Saudi energy officials – not too high to hurt the global economy, not too low to hurt their own economy'.[4] But if this is true why, when prices began to rise again—in early July 2007 they are above $70—was more oil not produced to keep prices within this desirable range? The same article noted, 'Mr. Naimi, the Saudi oil minister, borrowing the manner of a careful central banker, is rarely explicit about his plans. His every word is dissected by legions of analysts for the slightest hint of an inflection in policy.'

We do know—as discussed in Chapter 3—that in the 1980s Kuwait and then other oil producers reported substantially increased reserves, probably for political or financial reasons rather than because oil had been discovered. We know too that Kuwait may be in the process of restating its reserves to half of what was reported in 2005. This appears to be being done in part because the lower estimate seems to be more accurate and in part as an expression of becoming a more open society.

Saudi Arabia also reported a major increase in reserves, in 1990, by more than 50 percent.[5] It's possible that amounts were overstated and that there is now not enough oil in the ground to sustain further growth in production. (We observed in Chapter 3 that production declines when about half the available oil has been extracted.) If this is true, and if there is further pressure on Saudi Arabia to provide information about its oil industry, there could soon be a downward restatement of reserves that could have a major impact on how future availability of oil is perceived. Rumours could be as alarming as reports by Saudi Aramco, the government-owned company responsible for Saudi Arabian oil production.

The importance of Saudi Arabia's production to future availability of oil has been stressed often. For example, in its 2004 *World Energy Outlook*, the International Energy Agency (IEA) argued, 'Of the projected 31 mb/d [million barrels a day] rise in world oil demand between 2010 and 2030, 29 mb/d will come from OPEC Middle East … Saudi Arabia, Iraq, and Iran are likely to contribute most of the increase'.[6] Iraq was in turmoil in 2004 and still is. Iran's production may have already reached a peak (see the next paragraph). Thus, this analysis suggests that the largest part of the increase in world production until 2030 would have to come from Saudi Arabia.[7] But what if Saudi Arabia has reached a peak at about its current daily production of less than 9.5 million barrels a day (see Figure 6.1) and could contribute nothing more to a growth in oil production, let alone the further 20 mb/d implied by IEA's statement? At a minimum, confidence that oil production could continue to increase for a few more decades could be undermined. This could lead to panic buying—including hoarding by speculators—and rapid price escalation.

So far, evidence of oil depletion has not compelled action, even though production in six of the world's ten major oil-producing countries appears to be at a peak or in decline. The six, in order of their rank in oil production, are the US (3), Iran (4), Mexico (5), China (6), Venezuela (8) and Norway (9). If the leading producer, Saudi Arabia, were also judged to be in decline—leaving only Russia (2), Canada (7) and the United Arab Emirates (10) with growing oil production—the