Transportation in the post-carbon world

by Richard Gilbert and Anthony Perl

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Gilbert and Perl are the co-authors of Transport *Revolutions: Moving People and Freight Without Oil* (New Society, 2010, 2nd edition).

Introduction

One aspect of modern life that that will change dramatically during the post-carbon adjustments examined in this volume is our approach to developing and delivering mobility, and our expectations from the resulting transport options. The carbon-fueled motor vehicles, aircraft and marine vessels we now rely on have offered ongoing improvements in their economy, convenience and reliability over a long enough time period that all but a few transport professionals have come to take their smooth functioning for granted. As in other domains, cheap and abundant carbon fuels have made it easy to expand the quantity of mobility, without stimulating major efforts to make that mobility more energy efficient. But, with some 94 percent of transport currently fuelled by a derivative of crude oil,[1] our mobility modes are positioned to be on the leading edge of change that is driven by the need to shift energy sources.

In this chapter, we present the concept of a 'transport revolution' as a concept to guide thinking about the mobility changes that lie ahead. Transport revolutions will differ significantly from the incremental changes in mobility that have been the norm over the past 25 years, and indeed over most of history. Appreciating the differences between revolutionary change and incremental adjustments will be useful in pursuing transition strategies that can move more people and freight without oil before it is too late to avoid a global energy crisis.

Transport Revolutions: the fast track to post-carbon mobility

Successful post-carbon transitions will benefit from understanding the dynamics of transport revolutions. We define a transport revolution as being a substantial change in a society's transport activity – moving people or freight, or both – that occurs in less than 25 years. 'Substantial change' means one or both of the following: an ongoing transport activity increases or decreases dramatically, say by 50 per cent, or a new means of transport becomes prevalent to the extent that it is made use of by 10 per cent or more of the society's population. By our definition, a breakthrough in transport technology is not a transport revolution. If the breakthrough changes the way in which people or freight move, it could make a revolution possible. Most but not all transport revolutions depend on major technological improvements.

[1] For oil's share of all transport fuel, see Page 622 of IEA (2009).

For much of history, people have advanced their capacity for mobility through a long line of modest improvements in their ways of moving about. Tinkering with wheels, sails and engines has accumulated to produce significant transport advances. But, more than such fine tuning will be required to enable the rapid adjustment of transport systems to impending energy challenges. Transport revolutions, such as those analyzed in our book of the same name,[2] will be needed to keep ahead of oil depletion. The changes will have to be far-reaching enough to break entrenched organizational structures and user expectations.

In *Transport Revolutions*, we examine five episodes of rapid change in mobility. They include the inauguration of modern railway operations in England in the 1830s and the introduction of the overnight package delivery service in the United States during the 1980s. Each one of the five, and others we could have focused on (e.g., the introduction of containers into American freight transport in the 1950s), illuminates differences between radical shift and incremental adjustment that will be relevant for transitions to post-carbon mobility.

Transport revolutions over the next 25 years could have two predominant features. Some revolutions will involve maintaining the same or even higher levels of transport activity but in different ways from the present. An example could be continuation of the current level of freight movement between cities but with very much more of it performed by rail than by road. Some revolutions will involve large declines in transport activity. An example would be travel between continents, which could fall steeply because of economic decline or because no reasonable substitute for oil-fuelled aviation emerges.

Economic decline could characterize what might be regarded as a 'hard landing' into oil depletion. Rising demand for oil constrained by supply could push up prices to a level that reduces overall economic activity. As we discussed in the second edition of *Transport Revolutions*,[2] such a process was a feature of the recession that began in 2008, during which much transport activity fell. Even before the dramatic spike in oil prices and the economic crisis of 2008, there was a growing preoccupation with looming economic decline and societal collapse that could follow such a hard landing.[3] These dark visions posited, among other problems, a failure to keep society mobile in an era of energy constraints. We have argued that trying to adapt oil-based transport systems incrementally during such an era of oil depletion – i.e., falling oil production – would likely yield a repeating vicious cycle of high oil prices, economic recession, declining oil prices, modest economic recovery, and newly rising oil prices. Such grim outcomes would be the most likely path to a hard landing of widespread deprivation and intensified conflict.

The alternative route, which we characterize as a 'soft landing,' would arise from transport revolutions that refashion the current tight linkages between mobility and oil-based energy sources. In a soft landing, new transport systems would introduce growing capacity to move people and goods without oil such that demand for oil falls ahead of constrained supply. High oil prices and consequent economic turmoil – and even intense geopolitical conflict – could thus be avoided. We believe that such a soft landing is possible. Its key requirements are transport revolutions that, without oil or with very much less oil, allow continuation of humanity's gains in comfort, convenience, productivity and freedom from want.

Grid-connected vehicles: proven technology that can lead a shift to electric mobility

Over the next two or three decades motorized land transport will become mostly propelled by electric motors (EMs) rather than by the internal combustion engines (ICEs) that propel most of today's land transport. This shift of motive power would bring many benefits. Electric vehicles are quiet, energy-efficient, require little maintenance, have good acceleration at low speeds, and emit essentially no pollution at the vehicle. The challenge inhibiting such a shift has always been that of delivering sufficient quantities of electricity to the motor or motors.

Most electric vehicle research and development efforts in the U.S., Europe and Asia have pursued advances in storing electricity on board vehicles, in batteries and other storage devices, or generating electricity on board

[2] Gilbert and Perl (2010).
[3] See, for example, Jacobs (2004), Diamond (2005), and Kunstler (2005). In reprising his recent book, The Upside of Down (Island Press, 2006) Thomas Homer-Dixon described the crux of the current predicament as this: 'Our global system is becoming steadily more complex, yet the high-quality energy we need to cope with this complexity will soon be steadily less available' (Homer-Dixon, 2007).

vehicles, using fuel cells or ICEs. Work on storage devices and fuel cells has so far not brought electric traction to near the low cost and high effectiveness of ICE-propelled vehicles. Work on on-board generation using ICE-based generators has been fruitful – the Toyota Prius is the most widely used such automobile – but such hybrid ICE-electric vehicles are as dependent on oil as pure ICE vehicles and use only a little less oil-based fuel in typical driving.

The surest path to expanding the share of trade and travel met by electric mobility would be to expand the use of grid-connected vehicles (GCVs). For GCVs, electricity is generated remotely and delivered directly by wire or rail to the motor as the vehicle moves. GCVs are responsible for the most movement of people and freight by electric vehicles today. In a transport revolution that features a soft landing, we would expect this lead to continue, even as many more electric vehicles come into use, because of GCVs' especially high energy efficiency.

GCVs' advantages over battery electric vehicles (BEVs) would justify their primacy in the transition away from carbon-based energy sources. No matter how good BEVs might become, they will still need carry a large weight of batteries, which can amount to several hundred kilograms. These batteries take up space and their weight increases the vehicle's energy consumption. A GCV needs no battery, or a relatively small one for limited 'off-wire' travel. A GCV is subject only to energy distribution losses in moving the electricity from its source (e.g. a wind turbine) to the motor. For a BEV, as well as these distribution losses there are losses when charging and discharging the battery that can amount to several times the distribution losses.[4]

Unlike pure battery-electric vehicles, which disappeared early in the automobile's evolution and which have proven challenging to reintroduce, GCVs have been in use for at least as long as vehicles using ICEs. Electric streetcars and trains were operating in many cities at the end of the 19th century. Today, about 150 cities around the world have or are developing electric heavy rail (e.g. "metro" and "commuter" rail) systems running at the surface, elevated or, most often, underground. Some 550 have streetcar or light-rail systems, including 72 cities in Russia and 70 in Germany,[5] and about 350 have trolleybus systems.[6]

Electrification of intercity railroads began early in the 20th century, although most of it has occurred after 1950. Now most routes in Japan and Europe are electrified. Russia has the most extensive system of electrified rail, approximately half of the total of 85,000km, including the whole of the 9,258km Trans-Siberian Railway, for which electrification was begun in 1928 and completed in 2002. China's rail system is being rapidly electrified and is now boasts the second most extensive electrified system: 49 lines totaling about 24,000km. In these countries and elsewhere, these are mostly main routes and thus carry a disproportionately large share of passengers and freight. The revolution caused by introducing high-speed electrified passenger rail has transformed the way that people move between major cities in Japan and Western Europe.[7]

As well as freight trains, other types of GCV have been and are used to move goods. These include diesel trucks with trolley assist such as were used in the Quebec Cartier iron ore mine from 1970 until the mine was worked out in 1977. These trucks were in effect hybrid vehicles with electric motors powered from overhead wires that provided additional traction when heavy loads were carried up steep slopes. A diesel generator provided the electricity. The reported result was an 87 per cent decrease in diesel fuel consumption and a 23 per cent increase in productivity.[8]

Several direct comparisons of energy consumption by GCVs and comparable vehicles with diesel-engine drives confirm that energy use *at the vehicle* is invariably lower. For example, in 2008 San Francisco electric trolley buses used an average of 0.72 megajoules of energy per passenger-kilometer (pkm); in contrast, the average for

[4] The GCV is subject to a distribution loss of about 10 percent, which could fall with improved technology. A BEV with current (nickel hydride) batteries is subject to an additional charge-discharge loss of about 30 percent (Matheys et al, 2006). The charge-discharge loss could be below 10 percent with advanced lithium-ion batteries (Hedström et al, 2006).

[5] See Taplin (2006).

[6] See Trolley Motion at http://www.trolleymotion.com/en/.

[7] For details on this high speed rail revolution, see Chapters 1 and 6 of Gilbert and Perl (2010).

[8] See Hutnyak Consulting (2001).

diesel buses in the same city was 2.67MJ/pkm.[9] If the electricity for the trolley buses were produced by a diesel generator operating at 35 per cent efficiency, with a 10 per cent distribution loss, they would still use less energy overall than diesel buses. When electricity is produced renewably, what counts is energy use at the vehicle.

Electricity is the ideal transport fuel for an uncertain future. Unlike other alternative energy transition paths for transport, only electric mobility can move people and goods using a wide range of energy sources. Electric vehicles can use electricity produced from hydroelectric sources, wind turbines and photovoltaic panels, and from steam-turbine generating stations fuelled by coal, natural gas, oil, enriched uranium, wood waste, solar energy, or any combination of these sources. Thus, whatever the exact paths of the transitions towards renewable generation of electricity, transport systems based on these vehicles can readily adapt. They will not have to be changed each time a primary energy source changes. The energy requirements of transport systems will not limit innovation in energy production systems either. The challenge will be moving to electric mobility fast enough to keep ahead of oil depletion. Electric traction's flexibility in respect of its ultimate energy sources is an important reason for favoring GCVs as the leading edge of such a transition.

How to anticipate transport's post-carbon redesign

In this section, we illustrate a scenario for redesigning the movement of people in the United States to reduce oil consumption by 40% in 2025 and maintain a stable level of total mobility. The analytical effort supporting this scenario includes five steps:

- First, set the desired energy use and transport activity parameters for the system redesign. In our scenario, we have sought a 44 per cent reduction in America's use of liquid fuels between 2007 and 2025 and essentially no change in motorized transport activity (actually a one per cent increase in person-kilometers).[10]
- Second, estimate current transport activity and energy use.
- Third, anticipate what the available modes will be in 2025 and their unit energy use.
- Fourth, develop a plausible balance of modes that matches the levels of transport activity and energy use in 2025 to the established parameters.
- Fifth, continuously improve of energy use estimates and expectations of future transport activity.

The particular values for transport activity and unit energy consumption for 2025 that we set forth in Table 1 are less important than the process of developing and making use of such a table. Readers may well want to use different values, which may in turn require different balances among the modes. Our point is not that we have found the most appropriate values (although we have tried to identify them) but that the specification of a scenario such as that presented in Table 1 is an essential part of transport redesign.

We chose 2025 as the target year for several reasons. It is near enough to provide a meaningfully close target date that could motivate action – as opposed to simply planning for action – by incumbent 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. Moreover, 2025 will be a decade or so after we expect the occurrence of the world peak in production of petroleum liquids to have become evident. 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 scenario is the extent of the reductions in oil consumption that would be required by 2025. For this, we have estimated that world oil production – and consumption – in 2025 will be in the order of 26.3 billion barrels (bb).[11] This is only 15 per cent below the likely production in 2007 and it is

[9] The averages are based on data in the National Transit Database of the U.S. Federal Transit Administration at http://www.ntdprogram.gov/ntdprogram/data.htm.

[10] The logic for seeking a 44-percent reduction is developed fully in Chapter 5 of Gilbert and Perl (2010). It takes into account anticipated oil supply in 2025 and provides for larger reductions in consumption for developed than for developing countries.

[11] For the analysis behind this estimate of world oil production in 2025, see Figures 3.7 and 3.8, and the discussion of petroleum liquids production found in Chapter 3 of Gilbert and Perl (2010).

actually 7 per cent *above* production in 1990. However, ***the most important difference is that anticipated oil production of 26.3bb in 2025 would be 30 per cent below the projected 'business-as-usual' consumption of 37.6bb in 2025***. We propose that about two thirds of the shortfall be born by the richer countries, roughly corresponding to their share of total consumption in 1990.[12]

Table 1. Motorized movement of US residents in 2007 (estimated) and 2025 (proposed)

Values and totals in this table are rounded to aid comprehension	2007				2025						
Mode	pkm in billions (except per capita)	Fuel use per pkm, in MJ	Total liquid fuel use in EJ (GJ for per capita)	Total electricity use in EJ (GJ for per capita)	Local pkm in billions (except per capita)	Non-local pkm in billions (except per capita)	Fuel use per pkm in MJ	Total liquid fuel use in EJ (GJ for per capita)	Total electricity use in EJ (GJ for per capita)	Liquid fuel powered pkm	Electri-cally powered pkm
Personal vehicle (ICE)	7700	2.6	20.4		2500	2,500	2.1	10.5		5000	
Personal vehicle (electric)					1000		1.0		1.0		1000
Future transport					200		0.5		0.1		200
Local public transport (ICE)	50	2.8	0.1		100		2.0	0.2		100	
Local public transport (electric)	40	0.6		0.0	400		0.5		0.2		400
Bus (intercity, ICE)	200	0.7	0.1			500	0.5	0.3		500	
Bus (intercity, electric)						500	0.4		0.2		500
Rail (intercity, ICE)	6	0.9	0.0			100	0.6	0.1		100	
Rail (intercity, electric)	3	0.3		0.0		400	0.2		0.1		400
Aircraft (domestic)	950	2.0	1.9			600	1.8	1.1		600	
Aircraft (international)	330	2.3	0.8			400	2.1	0.8		400	
Airship (dom. and int.)						100	1.2	0.1		100	
Marine (dom. and int.)						100	0.7	0.1		100	
Totals	9300		23.4	0.0	4200	5200		13.1	1.6	6900	2500
Per capita	30,500		76.5	0.1	26,500			37.0	4.5		

Sources: Person-kilometers (pkm) for 2007 are extrapolated from data for 1995–2004 in Table 4.21M (aviation) and Table 1.37M (other modes) of United States Department of Transportation (2007). The split between ICE and electric intercity rail was estimated from the energy use data in Table 4.6M of the same source and an assumption that electric locomotives use about one third of the energy used by diesel-electric locomotives. The rates of energy use in 2007 are those in Table 4.15 of Gilbert and Perl (2010), p. 240, and are derived from the sources noted there.
Abbreviations in this table: ICE = internal combustion engine; pkm = person-kilometer(s); MJ = megajoule; EJ = exajoule; GJ = gigajoule.
Note: *Electric modes are in italics.*

We suggest that the cuts in oil used by transport should be proportionately larger than the overall reduction in oil use. This would allow for smaller cuts in, or even temporary maintenance of, consumption of currently essential uses of oil. These include the oil used as feedstock in chemical industries, particularly the production of fertilizers, pesticides and pharmaceuticals. In 2005 in the US, these and other non-fuel uses of oil comprised about 13.5 per cent of total oil use.[13] Such uses should be protected or even allowed to grow in proportion to population.

On the other hand, there will also be some replacement of petroleum oil for transport by liquid biofuels and by liquid fuels derived from coal. We do not expect more than a few per cent of total transport fuels to be replaced by such liquids. Biofuels could be constrained by land availability and soil depletion. Coal to liquids could be constrained by concerns about climate change and local and regional pollution. Production of both could be limited by their inherent energy requirements, which may well be unacceptable when global oil production is

[12] Table 5.1 of Gilbert and Perl (2010) shows that richer countries were actually responsible for 74 per cent of total oil consumption in 1990, and that the 2025 shortfall of expected supply in relation to "business as usual" (BAU) consumption will be 11.3 billion barrels. Allocating this shortfall as proposed in the text, richer countries use about 7.5 billion barrels less than the BAU projection, and poor countries would use about 3.7 billion barrels less. If consumption in richer countries were to rise no more before 2010 and then decline by 42 per cent to the 2025 target, this would require annual reductions in oil use across these 15 years by an average of about 3.6 per cent . If consumption by poorer countries were to rise by 25 per cent between 2007 and 2025, this would represent an average annual increase in consumption of 1.2 per cent.

[13] For non-fuel uses of oil, see Tables 1.15 and 1.3 of US EIA (2007).

declining. We assume here that the yield of other liquid fuels will offset the greater cuts to be required of oil for transport. Thus, the net result would be a cut of about 30 per cent in the use of oil and other liquid fuels.

Taking all these considerations into account, and allowing for a margin of error in the form of underestimation of the rate of production after the peak, we conclude that by 2025 richer countries should plan to reduce their use of liquid fuels for transport – almost all oil – by about 40 per cent below 2007 levels.

This oil reduction parameter is a key driver in our proposal for the revolution in moving people around the US by 2025, which is detailed in Table 1, which provides comparisons with the likely transport activity and energy use for each mode in 2007. A key underlying feature of Table 1 is that the US population is projected to grow by 16 per cent across this period, from 306 million to 355 million.[14] Accordingly, in some cases we have shown both total and per capita values.

We are not proposing that the motorized movement of people decline in direct proportion to the reduction in oil used by transport. Indeed, motorized person-kilometers would increase very slightly between 2007 and 2025 (by 1 per cent) although fall per capita (by 13 per cent). This would be achieved in two ways: by using oil more efficiently and by a substantial shift to electricity generated from other energy sources. Overall in 2025 compared with 2007, each liter of oil products would fuel about a third more person-kilometers. Electricity would fuel 27 per cent of the motorized movement of people in 2025 compared with about 0.5 per cent in 2007.

In our scenario, ICE-based personal vehicles (cars) will be providing just over half of the movement of people in the US in 2025, but much less than today's share, which is over 80 per cent. Their average energy consumption in megajoules per person-kilometer (MJ/pkm) will be about 20 per cent lower because of technical improvements and higher occupancies. Electric personal vehicles in 2025 will include cars and two-wheelers that have only electric motors and a declining number of 'plug-in hybrids', which can use a built-in internal combustion engine (ICE) but do so rarely.[15]

Future transport signifies the availability of new local transport options that may encompass electric jitneys and various kinds of on-demand transport including what is known as personal rapid transport (PRT).[16] By 2025, local public transport would have expanded substantially and become largely electrified. Electrified service would comprise a mix of modes: trolley buses, light rail (trams) and heavy rail (metro). Considerable reduction in MJ/pkm is anticipated in ICE-based transport, chiefly through higher occupancies, but less in electrified transport, which already operates with high efficiency and, as it expands, will encounter capacity challenges.

Intercity bus would also expand. About half of it would be powered by more efficient versions of today's diesel engines and half would be electric buses, drawing power for overhead wires that are installed for bus and truck use along some major highways. Intercity rail undergoes one of the largest increases by 2025, talking up some of the reduction in travel by car and replacing many short-haul flights under 500 kilometers. Most of the expansion would be by electrified rail, much of it providing high-speed service – more than 200 kilometers per hour (125 miles per hour). Unit energy use by ICE and electrified trains is expected to fall by a third, largely on account of higher occupancies. In the period until 2025, there would also be expansion of diesel-powered passenger rail service, over tracks not yet electrified, although eventually just about all rail, passenger and freight, will be powered by electricity.

Domestic aviation would have contracted substantially by 2025. A trend will be under way to use larger aircraft – because they are more fuel-efficient – flying over fewer routes, that is, those that can generate the high occupancies that will also be required to attain low levels of fuel use per person-kilometer. Modest reductions in unit fuel use are expected by 2025, chiefly on account of higher occupancies. Further reductions can be expected after 2025 as more of the fleet comprises large, efficient aircraft. International aviation would have expanded a

[14] The US population estimate and projection are from UNPD (2008).
[15] The average MJ/pkm is a conservative suggestion based on information in Table 3.3 of Gilbert and Perl (2010).
[16] The promise and prospects for PRT are discussed in Chapter 3 of Gilbert and Perl (2010). For anticipated energy consumption by PRT, see Gustavsson (1995).

little by 2025, although remaining about the same per capita. Its character would be changing towards movement of larger, more fuel-efficient aircraft flying over fewer routes, to be a much more prominent feature after 2025, when even international aviation will decline. By 2025 there would be some use of fuel-efficient, partially solar-powered airships for moving people over distances, particularly to remote locations for which service by rail or road is impracticable.[17]

There would be more use of water-based modes by 2025, particularly domestically in the form of coastal, lake and river ferries, but also by trans-oceanic vessels. The last especially could make considerable use of wind power through use of kites or solid sails.[18]

Conclusion: Three Pillars of Post-Carbon Mobility and the Vision Behind Them

Launching a transport revolution in the US along the lines described above will require three pillars to support efforts at steering change away from chaos and conflict. First would be establishment of an agency that can develop a detailed post-carbon mobility plan and facilitate its effective implementation. Second would be termination of existing programs and plans that expand airport and highway capacity for more oil-fuelled mobility, and a corresponding redeployment of human and financial resources towards introducing grid connected vehicles. Third would be imposition of an escalating tax on oil used for transport – perhaps reaching $0.50 per liter (about $1.90 per US gallon) within a few years. The proceeds would be used in part to induce individuals and businesses to retire what could soon be ‘stranded assets.’ These would include jet aircraft and motor vehicles that can be fuelled only by petroleum. The proceeds of the tax would also be used to stimulate private, state and local investment in electric mobility infrastructure in much the way that motor fuel and airline ticket taxes are used now for expanding aviation and road infrastructure.

These first steps away from the status quo would be among the most difficult moves made during the course of America’s impending transport revolutions. Interests vested in today’s oil-powered mobility would highlight and fiercely oppose the costs and disruption of change. The more numerous eventual beneficiaries of electric traction would be less motivated to support redesign, not least because its advantages could arrive further into the future. Most Americans would be unfamiliar with the transport alternatives being developed and thus uneasy at the prospect of such radical change. Communicating the risks of inaction in the face of oil depletion will require strong, effective leadership. In applying them to transport revolutions, the key to success will be articulating a vision of the future in which the quality of mobility can be seen to improve at the same time that the growth of travel slows down.

We close with a brief vignette of what such a vision could look like, in the hope that it will convince future leaders to advance it while inspiring most people to embrace it. For intercity trips up to 500km (about 300 miles), grid connected vehicles should require no more total travel time than today’s aviation system and highways. Planned and run well, new intercity mobility options could do away with much of the ‘hurry up and wait’ that adds time and stress to flying and driving. This includes waiting for increasingly invasive security procedures at airports waiting in traffic jams of road vehicles (gridlock) and aircraft queues for takeoff (winglock), waiting for connections through air hubs, and waiting to claim luggage that must be checked to keep a growing number of items that could be weaponized out of passenger cabins (e.g. liquids and gels). A well-run train and bus system will reduce the time and the discomfort of these travel experiences. Passengers on Japan’s Shinkansen (the original "bullet train") routinely arrive at their originating station just a minute or two before departure because there are no ticketing, luggage and security formalities to contend with. The Eurostar service linking London with Brussels, Paris and elsewhere has more elaborate pre-departure screening, with identity and luggage checks, but even there passengers are accepted up to 20 minutes before departure.

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17 The suggested unit fuel use by airships is speculative. A current operating company reports use of 1.3MJ/pkm for a 15-passenger vehicle (see Airship Management Services, http://www.airshipman.com/faq.htm). Larger airships and use of solar power from canopy-mounted connectors could reduce liquid fuel consumption substantially.

18 For towing kite applications for ships, see SkySails GmbH & Co, http://www.skysails.info.

Trains and buses can distribute travel time differently, with the longer journey offset by shorter waits to board, connect and collect one's belongings. The speed of the vehicle in motion will be slower than an aircraft, but travelers will reclaim minutes or hours that are consumed by today's unpleasant aspects of travel. More time spent aboard the vehicle will create the greater opportunity for undisturbed work and rest, as well as for taking meals and for the social interactions that are largely missing from contemporary flying and driving.

Even when the total journey time increases by many hours for land travel in the thousands of kilometers, and by days for voyages by sea, the experience will offer compensation. Wireless network connectivity, comfortable accommodations and appealing food and drink could offer the chance to work and play in motion that is today reserved for those who can afford first-class flying and luxury cruise ships.

Just as gourmets celebrate the emphasis on quality found in the 'slow food' movement, so too could post-peak-oil travelers appreciate the quality gained by slower motion. Taking the time to savor a relaxing, productive and enjoyable trip while it is happening could seem natural to future travelers. When they think about what came before, they may well look back on the twilight of the 'jet set' era – when passengers brought along their own food and drink, pillows, blankets and other creature comforts to survive no-frills flights – with the kind of bemusement with which their parents regarded photos of passengers packed into steerage accommodation on early 20th-century ocean liners.

If post-carbon transitions are successfully managed, then Americans of the 2030s will be incredulous at the ways in which Americans of the 2000s embraced the waste and discomfort of cramming onto planes and jamming roads with huge motor vehicles most often occupied by a lone driver. Today's vision will thus have become a reality, and the revolutionary mode of change that enabled it to be realized will again become the exception in adjusting our systems of mobility.

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