PREPARING TRANSPORT IN CHINA—AND THE REST OF THE WORLD—FOR OIL DEPLETION

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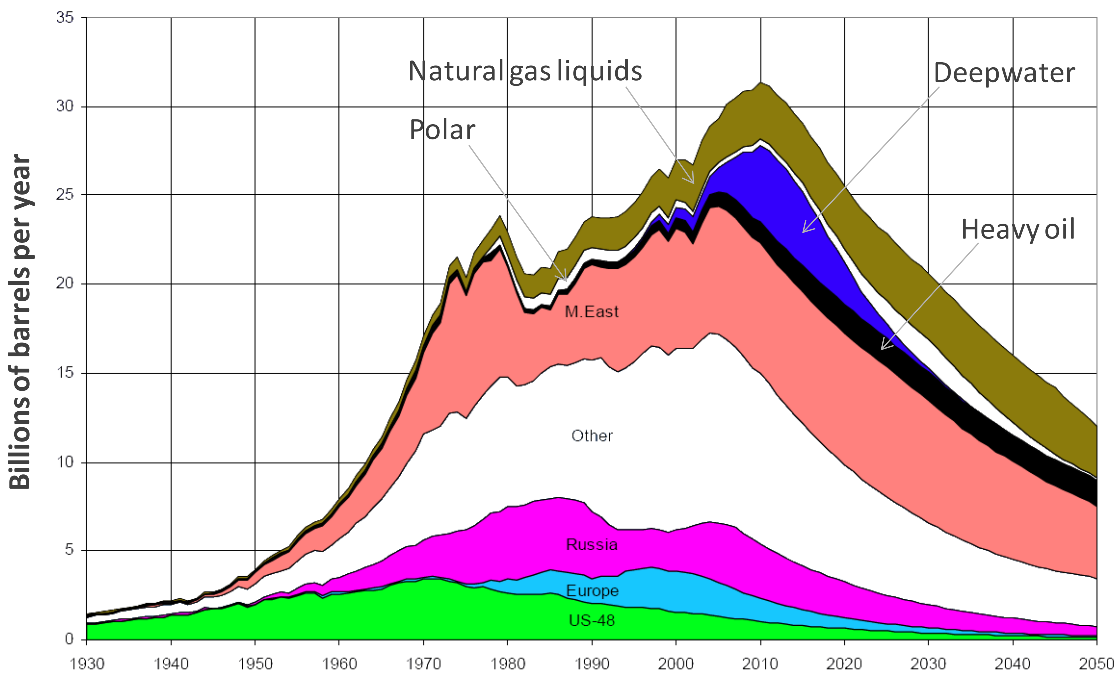
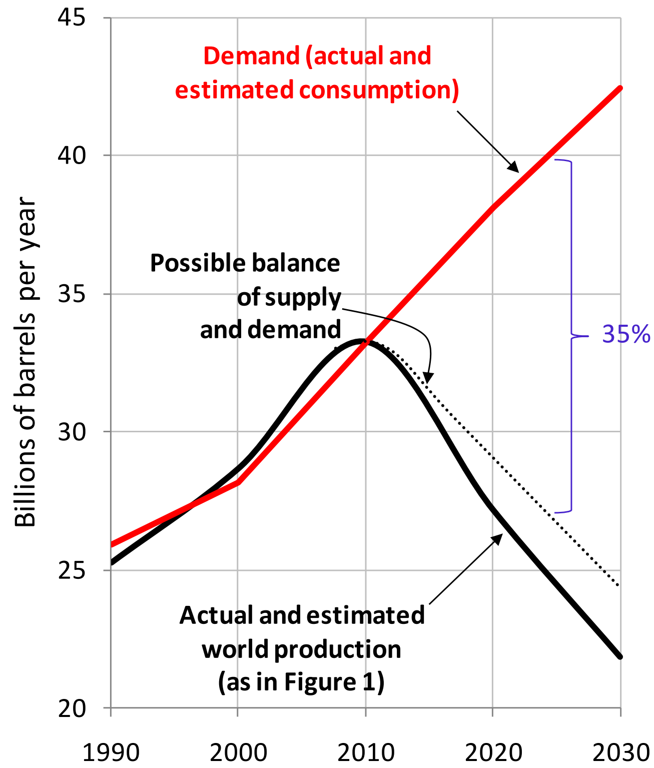
The main premise of this paper is that world oil production will peak in about 2010 and then decline (Figure 1). By 2025, production will be 35% below a 'business-as-usual' projection of

Figure 1. World production of petroleum liquids by source (conventional oil) or type (other), 1930 to present, and projections of production until 2050[1]



[1] Figure 1 is based on the work of geologist Colin Campbell and associates and is reproduced from Slide 59 of a presentation by Kjell Aleklett of the University of Uppsala, Sweden, at The Energy and Environment Conference, Shijiazhuang, China, November 2006, http://www.peakoil.net/Aleklett/Aleklett_Shijiazhuang.pdf.

***Figure 2. Estimated world production and consumption of petroleum liquids, 1990-2030*[2]**



consumption (Figure 2). Consumption cannot exceed production. They will be aligned by very high crude oil prices or by other factors that cause a substantial fall in demand for oil products. Demand could fall if there is much less travel and trade, a consequence of widespread economic collapse brought on by high oil prices. Demand for oil products could also fall if transport activity, now the main use of oil (see Figure 3 on the next page), were to become sustained by another fuel. This other fuel would likely be electricity.

Equity considerations suggest that richer countries should bear more of the burden arising from a shortfall in oil production. A reasonable allocation may be according to consumption in 1990, when richer countries consumed about 75% of oil production. If richer countries were to accommodate 75% of the impending shortfall, oil consumption in 2025 would be as indicated in Table 1. Oil consumption by richer countries would fall to 46% below their business-as-usual projection (40% below their level in 2007). Oil consumption by poorer countries would increase to 22% below their business-as-usual projection (23% *above* their level in 2007).

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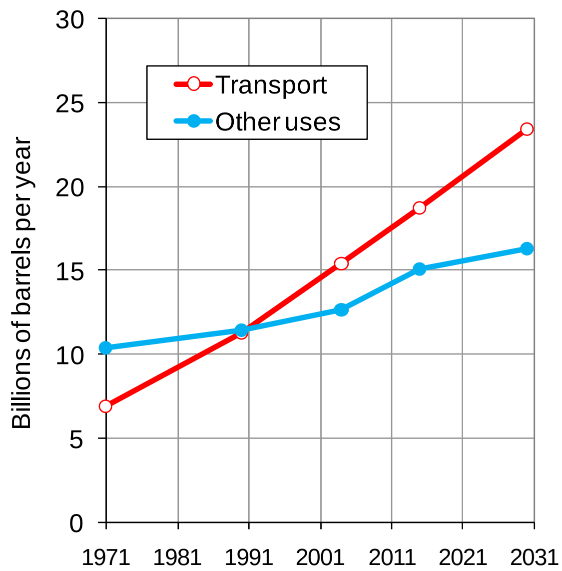
[2] The rising line in Figure 2 is the International Energy Agency's reference (business-as-usual) scenario for demand for petroleum liquids, at expected prices, as set out in *World Energy Outlook*, IEA, Paris, France, 2006. The other solid line is the envelope of world production from Figure 1. The dotted line represent a possible elevation of production as a result of high prices. In 2025, it is about 35% below projected demand.

Figure 3. Actual and projected consumption of oil for transport and for other purposes, 1971-2031[3]



Such an allocation could be mandated by an international body established to cope with oil depletion. It could happen without such a body. Poorer countries may have stronger imperatives to increase travel and trade, because of their low levels of transport activity. They may thus consume growing amounts of oil even while moving quickly to other fuels for transport. Richer countries could more readily maintain present or lower levels of transport activity during such transitions.

Table 1. Actual and projected world consumption of petroleum liquids and targets for richer and poorer countries for 2025[4]

	Actual 1990	Likely 2007	BAU projection 2025	Target 2025	Percentage differences of 2025 target from: Actual 1990	Likely 2007	BAU 2025
	Billions of barrels (bb)						
Richer countries	18.8	20.3	22.4	12.2	-35%	-40%	-46%
Poorer countries	5.8	11.5	18.0	14.1	+145%	+23%	-22%
World	24.5	31.8	40.4	26.3	+7%	-17%	-35%

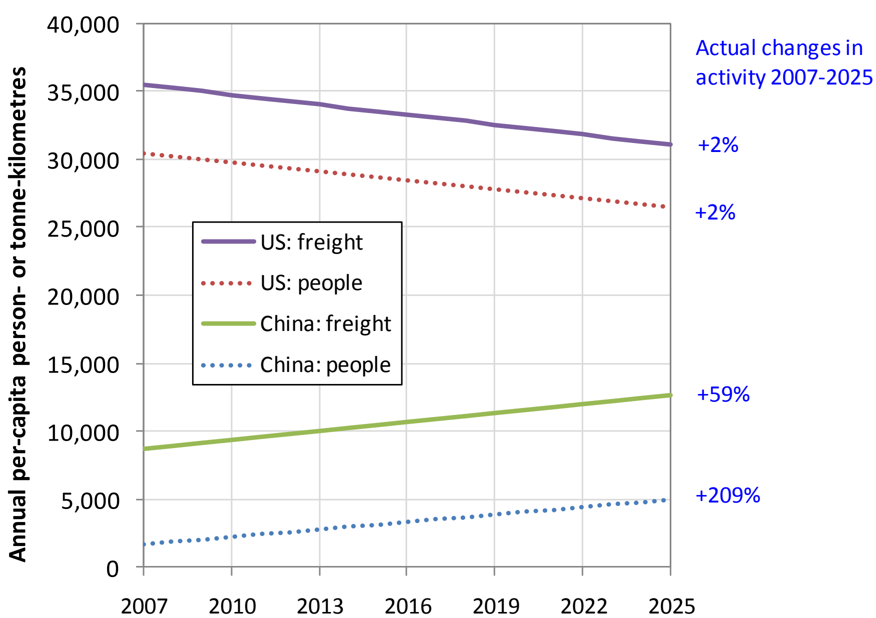
[3] Figure 3 is based on data and projections in several editions of *World Energy Outlook*, International Energy Agency, Paris, France, 2000, 2004, 2006.

[4] Actual and projected consumption is from the source detailed in Note 2. BAU means 'business as usual'. 'Richer countries are OECD member countries and former USSR and Eastern Europe. Others are 'poorer countries'.

The above analysis was developed in a recent book[5] that applied the analysis to China and to the United States of America (US), the most challenging cases among richer and poorer countries. A key feature of that application is the assumption that oil consumption and production can be brought into alignment by a combination of high oil prices and actions to reduce consumption of oil products, *while maintaining or increasing overall levels of transport activity*. Scenarios involving major declines in transport activity, resulting from economic collapse or other causes, were not explored.

In seeking to figure out how China and the US could accommodate oil depletion, movement of freight in, to and, from China was assumed to grow by 59% between 2010 and 2025, as shown in Figure 5. Movement of people was assumed to grow by more because this aspect of transport is even less developed in China and other poorer countries when compared with richer countries. Meanwhile, movement of both people and freight in, to, and from theUS was assumed to grow slightly, although they would decline per capita.

Figure 4. Estimated and proposed per-capita levels of transport activity in China and the US, 2007 and 2025[6]



[5] Gilbert, R, and Perl A, *Transport Revolutions: Moving People and Freight without Oil*, Earthscan, London, UK, 2008.

[6] Estimates for 2007 in Figure 4 are based chiefly on *China Statistical Yearbook 2007*, National Bureau of Statistics of China, China Statistics Press, Beijing Info Press, Beijing, China (available at http://www.stats.gov.cn/tjsj/ndsj/2005/indexeh.htm) and on *National Transportation Statistics 2006*, Bureau of Transportation Statistics, US Department of Transportation, Washington DC (available at http://www.bts.gov/publications/national_transportation_statistics/index.html).

Another key assumption—based on substantial analysis—was that electricity will be the only transport fuel that can replace oil products and support present or higher levels of transport activity. As will be illustrated below, availability of renewably produced electricity seems essentially limitless. The numerous potential sources include direct solar energy used to power furnaces and photovoltaic cells, marine energy, geothermal energy, and wind.

Moreover, when compared with the present means of powering motorized transport—i.e., by internal combustion engines (ICEs) fuelled by oil products—powering by electric motors (EMs) has numerous advantages and only one, albeit major, disadvantage.

In brief, the advantages of EMs over ICEs are these:

Torque: EMs provide maximum torque at zero or near-zero revolutions, i.e., when maximum torque is required. An ICE's maximum torque is typically delivered at several hundred or thousand revolutions per minute, requiring much gearing to move a stationary vehicle. EMs' high torque at low speeds contributes to their superior performance in stop-start conditions and during acceleration.

Reverse operation: Through regenerative braking, EMs can capture and store kinetic energy during deceleration, potentially reducing energy consumption.

Efficiency: EMs typically convert well over 90% of applied energy to traction.[7] Gasoline engines normally convert no more than 30% of applied energy; diesel engines convert up to 45%.[8] Although the unit energy cost of electricity is often higher than that of liquid fuels, the cost per unit of traction energy is usually lower, and the gap is mostly widening in electricity's favour.

Power per unit weight or unit volume: For a given power output, EMs are much smaller than ICEs, even without the ICEs' required emission control systems. Setting aside the matter of energy storage—the disadvantage discussed below—EMs' higher power/weight ratios mean that EMs use less energy to move the traction system. Their higher power/volume ratios provide more room within the vehicle.

Little or no pollution at the vehicle: Almost all the pollution from operation of an ICE vehicle consists of the products of fuel combustion at the vehicle. Electric traction has no such products although it may be responsible for atmospheric pollution where the electricity is generated.

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[7] Åhman, M, Primary energy efficiency of alternative powertrains in vehicles, *Energy,* November, vol 26, no 11, pp973–989, 2001.

[8] These efficiencies are cited by the Volvo company at http://www.volvo.com/group/global/en-gb/Volvo+Group/ourvalues/environment/products/dieselengines.htm.

Overall, pollution from generation is usually less per vehicle-kilometre and, having fewer sources, is intrinsically more controllable.

Silence: ICEs harness controlled explosions of fuel and air mixes. They are intrinsically noisy. Their noise can be substantially muffled, but at the cost of reduced energy efficiency. EMs are almost silent in operation. Indeed, the quietness of EVs has been considered dangerous to blind people and others.[9]

Simplicity: EMs typically have one or a few moving parts. ICEs typically have hundreds of parts. In principle, EVs are inherently more durable, reliable, and cheaper to maintain.

Flexible as to ultimate energy source: EVs that use externally supplied electricity are indifferent as to how the electricity is generated. Nothing has to change at the vehicle if the fuel for electricity generation changes. Such EVs are thus readily compatible with transitions to renewable generation. ICEs, by contrast, usually need substantial modification to accommodate change from the energy source(s) for which they were designed.

The one disadvantage of EMs is the energy density of their fuel as stored. The liquid fuels used for ICEs have high usable energy content per unit weight or volume. The available energy densities of gasoline and diesel fuel are both close to 45 megajoules per kilogram. That of a nickel metal hydride (NiMH) battery—a type often used in EVs—is about 0.25 MJ/kg.[10] Thus, a NiMH battery would have to be about 180 times as heavy as a full gasoline tank to provide the same amount of usable energy (and occupy about 100 times as much space). Allowing for the typical efficiencies of conversion to kinetic energy noted above, the effective energy density of gasoline is about 50 times that of a NiMH battery; that of diesel is greater. Lithium ion batteries are two to three times more energy dense than NiMH batteries, reducing gasoline's advantage to about a factor of 20.

This disadvantage allowed ICE-based vehicles to prevail during the 20th century, and will continue to do so as long as oil products are affordable. The prospect of closing the gap in energy storage capacity to less than a factor of about five may be remote.[11]

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9 For example, see See Flandez, R, 'Blind pedestrians say quiet hybrids pose safety threat', *Wall Street Journal*, 13 February 2007, http://online.wsj.com/public/article/SB117133115592406662-7BH5dNRG2MssUH28WlvpqNMnCy8_20080212.html

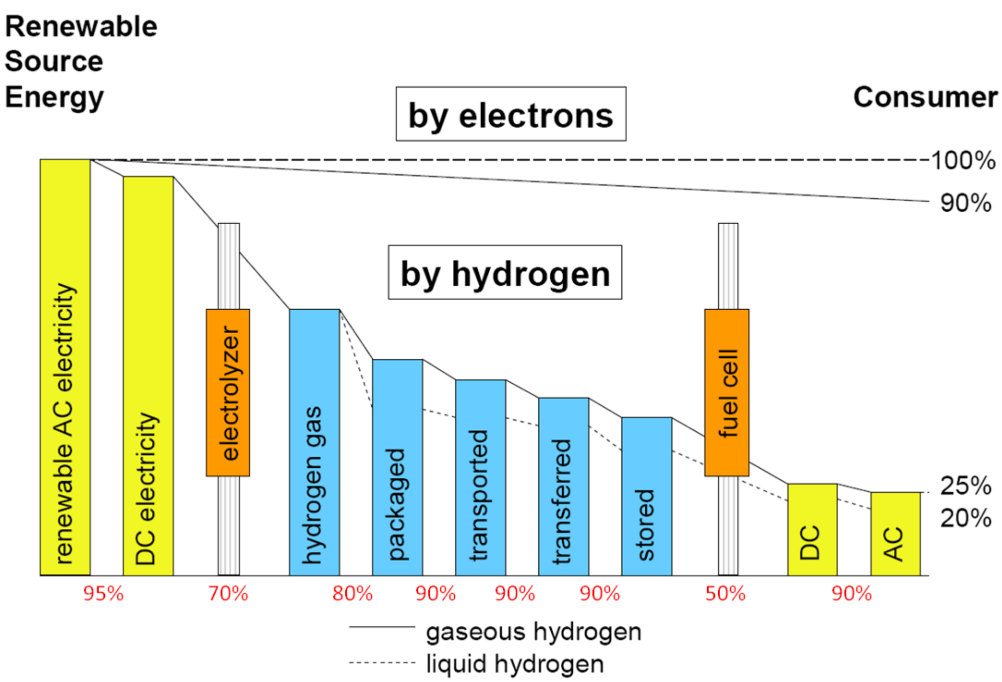
10 This estimated energy density is from Figure 3-1 of Kalhammer, FR, et al, *Status and Prospects for Zero Emissions Vehicle Technology: Report of the ARB Independent Expert Panel*. State of California Air Resources Board, Sacramento, CA, April 2007. In that source, energy density is given in Wh/kg (70 Wh/kg ≈ 0.25 MJ/kg).

11 Presently, the most ambitous projection of energy density for a storage system for electric vehicles is that for the Electrical Energy Storage Units (EESUs) under development by the EESTOR company. These capacitor-based units are projected to have an energy density of about 1.2 MJ/kg, i.e., about twice that of current lithium ion

A way of circumventing the challenge of storing electricity on vehicles is to generate it on board the vehicle. This is most often done using a generator powered by an ICE, as in diesel-electric locomotives and most hybrid electric-ICE automobiles. Such an arrangement provides for favourable performance features, particularly at low speeds, and thus can contribute to accommodation of oil depletion.

There has been much research and development into on-board generation whereby electricity would be generated by fuel cells fuelled by hydrogen. This work has encountered several challenges, notably in the unreliability of fuel cells and the difficulties of storing and distributing hydrogen. Nevertheless, the hydrogen-fuel-cell system is considered attractive, chiefly because while in operation it produces only water and because hydrogen can be produced renewably. Electricity generated by wind turbines, for example, can be used to make hydrogen by electrolysis of water. Such concepts encounter another challenge: the cumulative energy losses that occur during multiple energy transformations, illustrated in Figure 5.

Figure 5. Losses when energy is moved from source to vehicle via electrons and via hydrogen [12]



batteries. (See the EESU patent at http://www.patentstorm.us/patents/7033406/fulltext.html.) If this projection is realized, the effective energy density of an ESSU will be one tenth that of gasoline.

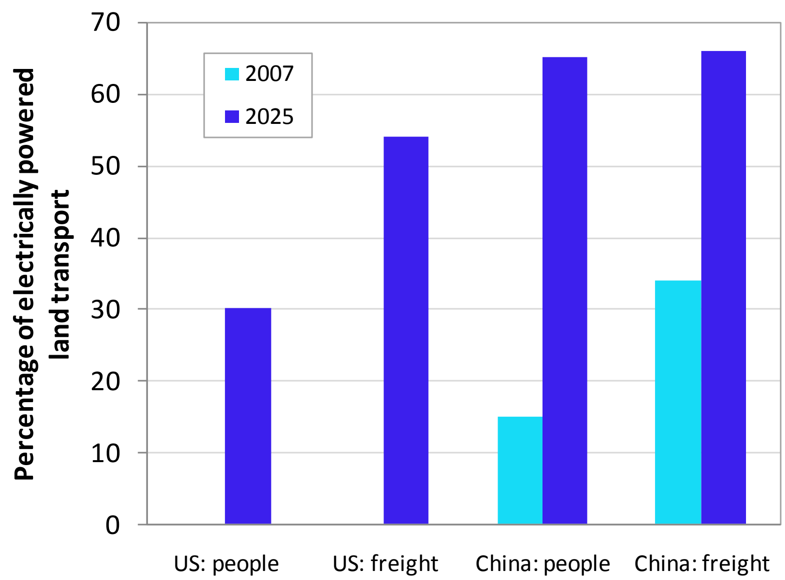
12 Figure 5 is based on Figure 9 of Bossel, U, *Does a Hydrogen Economy Make Sense?* European fuel Cell forum, Oberoohrdorf, Switzerland, 2005. Available at http://www.efcf.com/reports/E13.pdf. The numbers under the bars show the conversion efficiencies of the processes.

Figure 5 shows the losses for the transformations in producing hydrogen from electricity and then using the hydrogen to make electricity. The cumulative loss is 75% or 80% according to whether the hydrogen remains in gaseous form or is liquified. This total loss may be compared with the typical loss of 10% when electricity is generated, say, at a wind turbine, and then used to power electric traction at a distant location, illustrated in the upper part of Figure 5.[13]

Such direct powering through the electricity grid is the other means of circumventing the challenges in storing electricity on board vehicles. This is a highly efficient means, used extensively for public transport vehicles including trains, streetcars, and trolley buses. It is also used in mines and other off-road places for powering trucks. In principle, grid connection could also be used to power personal vehicles, whether driven by an occupant or automated.[14]

Table 2 on the next page shows how the movement of people in China and the US could meet the oil consumption and transport activity parameters set out in Table 1 and Figure 4, chiefly through conversion to electric traction. Table 3 on Page 10 does the same thing for the movement of freight. Figure 6 shows the shifts to electric traction in each case.

Figure 6. Actual and proposed shares of electrically powered land transport, China and the US, 2007 and 2025 [15]



13 An example of direct powering of electric traction by renewable energy is the light-rail system in Calagary, Alberta, Canada. This system is entirely fuelled from 12 660-kW wind turbines whose output is transmitted across the Alberta grid. The system's slogan is 'Ride the Wind'.

14 The concept of Personal Rapid Transit (PRT) embraces grid-connected personal vehicles. For a useful discussion of PRT, see NETMOBIL *EU Potential for Innovative Personal Urban Mobility,* NETMOBIL project, University of Southampton, UK, 2005. Available at http://www.eukn.org/binaries/eukn/dg-research/research/2005/10/netmobil-d7-eu-potential-final.pdf.

15 The sources for the amounts of transport activity in 2007 are those detailed in Note 6.

Table 2. Achieving reductions in oil use for the movement of people in, to, and from China and the US, 2007 and 2025[16]

Amounts of activity for 2007 and 2025 are in billions of person kilometres, except per-capita amounts

	US: transport activity				China: transport activity		
Mode	**2007**	**2025**	**2025/2007**		**2007**	**2025**	**2025/2007**
Personal vehicle (ICE)	7,700	5,000	0.6		500	1,250	2.5
Personal vehicle (electric)		1,000			200	1,500	7.5
Future transport (PRT, etc.)		200				500	
Local public transport (ICE)	50	100	2.0		300		
Local public transport (electric)	40	400	10.0		30	1,000	33.3
Bus (inter-city, ICE)	200	500			500	500	1.0
Bus (inter-city, electric)		500				500	
Rail (inter-city, ICE)	6	100	16.7		300	100	0.3
Rail (inter-city, electric)	3	400	133.3		300	900	3.0
Aircraft (domestic)	950	600	0.6		150	150	1.0
Aircraft (international)	330	400	1.2		50	100	2.0
Airship (dom. and int.)		100				100	
Marine (dom. and int.)		100			5	100	20.0
Totals	9,300	9,400	1.0		2,350	7,250	3.1
Per capita	30,500	26,500	0.9		1,750	5,000	2.9
Total electrically powered	45	2,500	55.6		730	4,400	6.0
Mean MJ/pkm for ICI-based movement	2.5	1.9	0.8		1.5	1.1	0.7

Table 2 shows that ICE-based automobiles would provide for most of the motorized movement by US residents in 2025, although the actual amount would have fallen by 40%. Most of the difference would be performed by personal vehicles, but with electric traction. Aviation would be equally reduced, but would still be a major mode of domestic travel. Reductions in travel by personal vehicle and by air would be offset by increases in travel by local transit and by inter-city bus and train, all of which would be undergoing rapid electrification.

16 The sources for amounts of transport activity in 2007 are detailed in Note 6.

Table 3. Achieving reductions in oil use for the movement of freight in, to, and from China and the US, 2007 and 2025[17]

Amounts of activity for 2007 and 2025 are in billions of tonne kilometres, except per-capita amounts

	US: transport activity				China: transport activity		
Mode	**2007**	**2025**	**Change**		**2007**	**2025**	**Change**
Truck (ICE)	2,050	1,500	0.7		900	1,600	1.8
Truck (battery)		500				1,000	
Truck (trolley)		500				500	
Rail (ICE)	2,650	900	0.3		1,050	1,500	1.4
Rail (electric)		2,700			1,050	3,000	2.9
Pipeline	1,250	800	0.6		100	200	2.0
Air (domestic)	15	10	0.7		5	5	1.0
Air (international)	25	25	1.0		5	15	3.0
Airship (dom. and int.)		50				100	
Marine (domestic)	700	1,100	1.6		4,750	5,500	1.2
Marine (international)	4,200	3,000	0.7		3,750	5,000	1.3
Totals	10,900	11,100	1.0		11,600	18,400	1.6
Per capita	35,600	31,200	0.9		8,700	12,700	1.5
Total electrically powered		3,700			1,050	4,500	4.3
Mean MJ/tkm for ICI-based movement	0.8	0.6	0.9		0.5	0.5	0.9

In China, just about every means of motorized movement of people would exhibit increases by 2025, with the overall increase being about threefold, absolutely and per capita. As for the US, massive electrification would be under way.

This exercise suggests that oil depletion can be accommodated chiefly by progressive conversion to electric traction. It begs questions as to whether sufficient electrical energy could be made available, especially from renewable sources. The additional electricity generation

[17] The sources for amounts of transport activity in 2007 are detailed in Note 6.

required for the electric traction proposed in Table 2 and Table 3 is less than 10% of the generation expected to be in place each of in the US and China in 2025.[18]

Both China and the US have substantial potential for electricity generation from renewable resources. An estimate for the US suggested that renewables could feasibly provide 635 gigawatts of generating capacity by 2025, i.e., 60% of expected installed capacity.[19] The potential for electricity generation from renewable resources in China appears to be similarly large. One estimate suggested that the feasible potential is 815 gigawatts, almost twice the total installed capacity in 2007 and almost equal to the installed capacity expected in 2025.[20]

In conclusion, world oil depletion is beginning, and adjustments are needed to sustain human endeavours. For transport, the most important adjustment could be replacement of oil-fuelled traction by electric traction. Enough progress can be made by 2025 to accommodate oil depletion while sustaining transport activity in richer countries and providing for substantial growth in poorer countries.

So that richer and poorer countries can achieve a 'soft landing' into oil depletion, China and the US could perhaps assume leadership in assessing the extents of their own and others' vulnerabilities. Together they could help secure cooperative deployment of available world resources and support orderly transitions to the use of less oil for transport, chiefly through use of electric traction. The alternative could be an unthinkable 'hard landing' into oil depletion, characterized by very high prices and possible social and economic collapse.

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[18] This analysis taken from *Transport Revolutions* (detailed in Note 5), in particular Table 5.6 and associated text.

[19] ACORE *The Outlook on Renewable Energy in America*, American Council for Renewable Energy, Washington DC, 2007. Available at http://www.acore.org/theoutlook07.php. Of the 635 GW, about 15 GW would be provided by concentrating solar power (CSP). A US Department of Energy report for the Western Governors' Association suggested that using only available land with the most intense sunshine, over 6,800 GW of electricity could be generated by CSP in the Southwest, i.e., several times the total installed capacity of the US in 2007 of about 950 GW (documented on Page 7 of *Report to Congress on Assessment of Potential for Concentrating Solar Power for Electricity Generation*, US Department of Energy, Report DOE/GO-102007-2400, February 2007, available at http://www.nrel.gov/docs/fy07osti/41233.pdf). To put this another way: a circular area in the southwest US, about 150 kilometres across, covered with concentrating mirrors and turbines, could provide all the electricity now used in the US The ACORE report makes no mention of marine energy (from waves, tides, and currents) for which the potential may also be large.

[20] Cherni, J A, and Kentish, J, Renewable energy policy and electricity market reforms in China, *Energy Policy*, vol 35, pp3616–3629, 2007. This estimate did not include the huge potential for offshore wind turbines located on China's extensive continental shelf, said to be in the order of 750 GW (Feller, G, China's great potential: Wind power, *Power Engineering International*, vol 14, no 7, pp30–32, 2006).