New Transport Systems for the 21st Century

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Oil is important; its production will soon fall

Modern living depends profoundly on the motorized movement of people and freight, almost 95 per cent of which is fuelled by oil products. Worldwide, transport consumes more than 60 per cent of all oil – more than 70 per cent in North America – a share that is growing everywhere.[1] Other uses of oil may be more important than much motorized transport, including use as a feedstock for fertilizers, pesticides, pharmaceuticals, plastics, and other products.

Much oil remains below land and sea – and perhaps more oil-yielding material such as bitumen – but the oil that can be produced easily and inexpensively is being quickly used up. Strong evidence for this is the need of the energy company BP to exploit the Macondo Prospect, 4.1 kilometres below the seabed of the Gulf of Mexico, 1.5 kilometres deep at the point of drilling. The rig exploded in April 2010, caught fire, and sank, The pipe from the oil source was ruptured, damaging the wellhead at the seabed. Up to 10 million litres of crude oil have escaped into the Gulf each day.[2]

A confluence of circumstances point to the early beginning of what may be a gradual but inexorable decline in world oil production:[3]

- 50-60 per cent of global oil flows come from about 100 large oil fields, average age 50-60 years, most in decline
- super-giant oil fields were last found 50 years ago

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1 Data in this paragraph are for 2007 and are from International Energy Agency, World Energy Outlook 2009, IEA, Paris, France, 2009.

2 The information in this paragraph is from a variety of topical sources, including *Wikipedia*, and could be in need of verification. Deepwater Horizon, the rig from which exploratory drilling was being done, had in 2009 drilled the world's deepest well, to a depth of 10.7 kilometres below the surface of another part of the Gulf of Mexico.

3 These points are taken from a presentation by Matthew R. Simmons, Chairman Emeritus, Simmons & Company International (Energy Investment Bankers) at the AON Annual Energy Insurance Symposium, Houston, Texas, January 2010 (see http://www.simmonsco-intl.com/files/AON per cent20Annual per cent20Energy per cent20Insurance per cent20Symposium.pdf).

- there are no third-party audits for more than 90 per cent of the world's 'proven' oil and gas reserves
- rusting infrastructure and an aging energy workforce are almost insurmountable obstacles to maintaining possible oil supply.

The point about reserves is worth amplifying. The world's main repository of data on energy is the Paris-based International Energy Agency. IEA was recently accused by the UK government's former chief scientist of exaggerating oil world reserves by up to a third.[4] Problems with oil data extend beyond the reporting of reserves. For example, the U.S. government, usually exemplary in data matters, produces what seem to be questionable statistics on oil production.[5]

Also worth noting is the lack of obvious replacement for most of the anticipated decline in production from existing fields. Figure 1 suggests that, were oil to be available in 2028 under present conditions, world demand for it (consumption) would rise by some 15 per cent.[6] However, by that year production from existing and planned oil fields will fall by 40 per cent, resulting in a shortfall of 43 million barrels a day (half of current production) to be met from so-far unidentified sources of oil.

Figure 1 goes about here

IEA has suggested that such a shortfall would occur because: " … there is a problem of chronic under-investment by oil-producing countries, a feature that is set to result in an 'oil crunch' within the next five years that will jeopardize any hope of a recovery from the present global economic recession."[7]

A reason for the chronic under-investment could be that oil companies realize that there is little more oil to be found that can be extracted profitably.

[4] See Mason R, Oil reserves 'exaggerated by one third.' *Daily Telegraph*, March 22, 2010, at http://www.telegraph.co.uk/finance/newsbysector/energy/oilandgas/7500669/Oil-reserves-exaggerated-by-one-third.html. The former chief scientist warned of shortages and price spikes "within years."

[5] See Baskin B, Shortcomings Exposed in Oil Data: DOE Documents, Consultants' Report Cite Outdated Methodology, Errors in EIA's Weekly Survey. *Wall Street Journal,* March 18, 2010, at http://online.wsj.com/article/SB10001424052748703523204575130141392493862.html?mod=WSJ_Commodities_LeadStory.

[6] Figure 1 is from a presentation by Glen Sweetman, Director of the International, Economic, and Greenhouse Gases Division of the U.S. Energy Information Administration (EIA), at the EIA's 2009 Energy Conference, Washington DC, April 7, 2009, at http://www.eia.doe.gov/conference/2009/session3/Sweetnam.pdf.

[7] The quotation is from an interview of Fatih Birol, IEA's chief economist, by Steve O'Connor, reported in Warning: Oil supplies are running out fast. *The Independent*, August 3, 2009, at http://www.independent.co.uk/news/science/warning-oil-supplies-are-running-out-fast-1766585.html.

Oil depletion will cause economic havoc, unless demand falls first

Figure 1 suggests strongly that we are at or close to the peak in world production, to be followed by a long period of decline in production, known here as *oil depletion*. The projection of demand in Figure 1 would thus be impossible. Demand – i.e., consumption – cannot occur without supply. Economists suggest that an imbalance between potential demand for oil and supply of oil is usually resolved by a rise in the price of oil, which restrains consumption within the envelope of supply.

Demand bumping up against supply appeared to cause the oil price increases of the last decade, culminating in a price peak of $147 per barrel in July 2008, shown in Figure 2.[8]

Figure 2 goes about here

Oil prices had been rising since 2003, but the spike in 2008 was nevertheless remarkable, and the subsequent 75 per cent fall and recovery perhaps even more so.

According to one analyst, "A spike in the price of oil has preceded almost every U.S. recession and market crash for nearly half a century."[9] Accordingly, the recession of late 2008 may have been precipitated by the oil price spike, which then dramatically reduced consumption of oil, thereby collapsing its price. Other factors – e.g., sub-prime mortgages, shenanigans on Wall Street – could have set the scene for the oil spike to precipitate the recession, and could well have worsened it.

High oil prices can have widespread effects on the economy because transport, and thus oil-based transport fuels, is a factor in the cost of almost every product. The strongest effect may be on vehicle sales, because fuel prices also affect the cost of using these products. Figure 3 shows how U.S. sales of light-duty trucks (SUVs, vans, pick-ups) fell as oil prices rose steeply late in 2007 and in the first half of 2008.[10] Then, as the recession took hold, sales of regular automobiles fell too.

Figure 3 goes about here

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[8] Figure 2 is based on data from the U.S. Energy Information Administration at http://tonto.eia.doe.gov/dnav/pet/pet_pri_fut_s1_d.htm (Contract 1).

[9] The quotation is from a blog posting by Gail Tverberg at http://www.theoildrum.com/node/6025, specifically illustrated by Figure 8 in that posting.

[10] Automobile sales data in Figure 3 are from the U.S Bureau of Economic Analysis at http://www.bea.gov/national/index.htm (Motor vehicles). Oil price data are from the source detailed in Note 8.

Both General Motors and Toyota have said they are now planning for a long-term shrinking of the U.S. automobile market by about 30 per cent.[11] Such a shrinking may already be evident in Figure 3, which shows 2006 sales of some 16 million vehicles (the approximate rate for many previous years) becoming annual sales of some 11 million vehicles (apart from the blip in July 2009 caused by the 'cash-for-clunkers' program).

The high oil prices may also have affected transport activity in the U.S. This is illustrated in Figure 4, which shows a dramatic change in late-2007 in a long-established trend.[12] The decline in travel began just as oil prices began to rise very steeply (see Figure 2). It stopped when oil prices collapsed late in 2008.

Figure 4 goes about here

We may be in a vicious cycle: oil prices are boosted by scarcity and busted by recession, and also constrained by falling supply. The vicious cycle of oil price and economic recession may be reinforced by another cycle concerning investment in oil supply. The two cycles are shown in Figure 5.

Figure 5 goes about here

Humanity, though its dependence on transport and, in turn, on oil, appears to be between two rocks and a hard place.

- The two rocks are that oil prices above $80/barrel may be required to develop (a) any new oil supply and (b) alternatives to oil.
- The hard place is that a recession occurs whenever oil goes much above $80/barrel.

The result may be what economists call 'market failure': a situation beyond resolution by the usual workings of demand, supply, and price. The possibility of market failure impels consideration of rationing of oil products by a means other than price. Gasoline was rationed in Canada during the Second World War, but not since. Petroleum geology and economics may impel rationing again. One may well ask whether North American governments should embrace rationing of gasoline and diesel fuel as a way of bringing revolutionary but orderly change to transport industries.

[11] For GM's anticipation of a smaller auto market, see For U.S. auto sales, a long hangover awaits, June 8, 2009, at http://in.reuters.com/article/idINIndia-40155020090608. For Toyota's, see Kim C-R, Toyota's new boss warns of two more tough years, June 25, 2009, at http://www.reuters.com/article/idUSTRE55O0YB20090625. (The statement is assumed to apply to Toyota's U.S. sales, and perhaps other sales.)

[12] The data in Figure 4 are from the U.S. Federal Highway Administration at http://www.fhwa.dot.gov/ohim/tvtw/tvtpage.cfm.

Quebec is especially vulnerable, but is well-endowed with the best alternative fuel

Quebec has much reliance on imports of oil, especially from outside North America. Figure 6 and the associated table show that this dependence is greater than that of the U.S., where there is much concern about energy security.[13] Moreover, the U.S. maintains a Strategic Petroleum Reserve of up to 727 million barrels of crude oil. equivalent to two months of imports at the current rate. Quebec has no such reserve. Thus Quebec, which like the rest of North America depends almost entirely on oil products for transportation, is especially vulnerable to interruptions in oil supply.

Figure 6 goes about here

On the other hand, Quebec is especially well endowed with facilities for renewable production of what may be the best alterative transport fuel: electricity. In 2009, Hydro-Québec produced 189 terawatt-hours of electricity, 97 per cent renewably, and was able to export 12 per cent of this total.[14]

The main alternative to internal combustion engines (ICEs) fuelled by oil products and to electric motors is ICEs fuelled by biofuels. However, even at present levels of production, which are low in terms of transport's total requirements,[15] industrial biofuel production may be having a profound effect on food production and the costs of food. Estimates of how much the 2008 rise in food prices could be attributed to industrial biofuel production range from 20 to 75 per cent.[16] Accordingly, much effort concerns development of methods of industrial ethanol production from the cellulosic portion of non-food plants. A recent review concluded, "Among the currently and foreseeable commercial biofuels, only cellulosic ethanol has the potential to be produced and consumed on a sustainable basis … [but this fuel] will not be produced on a significant scale for another decade or so."[17]

[13] Figure 6 is based on Statistics Canada, *The Supply and Disposition of Refined Petroleum Products in Canada*, Catalogue No. 45-004-X, January 2010, at http://www.statcan.gc.ca/bsolc/olc-cel/olc-cel?catno=45-004-X&chropg=1&lang=eng.

[14] Data on electricity production and exports are from Hydro-Québec's *Annual Report 2009*, at http://www.hydroquebec.com/publications/en/annual_report/index.html.

[15] For example, in the U.S., a major producer and user of biofuels, production of ethanol displaced less than 4 per cent of oil use in 2009. See U.S. Energy Information Administration, *Petroleum, U.S. data*, at http://www.eia.doe.gov/oil_gas/petroleum/info_glance/petroleum.html.

[16] See ActionAid, *Meals per gallon: The impact of industrial biofuels on people and global hunger*, London: ActionAid UK, 2010, at http://www.actionaid.org.uk/doc_lib/meals_per_gallon_final.pdf.

[17] The quotation is from B.D. Solomon, Biofuels and sustainability, *Annals of the New York Academy of Sciences* 1185, 2010.

Grid-connected land transport may be the best means of reducing demand, especially with deployment of Personal Rapid Transport

A decade ago, the future of electric traction seemed linked to the development of fuel cells, which can produce electricity on board vehicles, usually through the low-temperature oxidation of hydrogen. The fuel-cell route to electric traction has turned out to be a cul-de-sac because of fuel cells' lack of reliability, high costs, and, above all, high energy losses.

Figure 7 illustrates the major disadvantage of fuel-cell-based traction: high energy losses.[18] The upper row indicates that making hydrogen from electricity and then making electricity from the hydrogen results in a total loss of 75 per cent of the initially produced energy, 80 per cent if the hydrogen is liquefied for transport and storage. By contrast, powering electric traction from a similar source but via the grid results in losses of only about 10 per cent. (The example is a Calgary light-rail train, which is 100 per cent powered by wind turbines, hence the slogan 'Ride the Wind.') In an energy-restrained society, a system that loses 75 per cent or more of initial energy production will not compete well with one that loses only 10 per cent.

Figure 7 goes about here

Producing electricity on board vehicles and delivering it to them while in motion represent two of three systems for powering electric traction. The third is to produce electricity elsewhere and store it on board vehicles in batteries or some other device. Battery-electric vehicles are a focus of much current work on electric traction. As replacements for ICE-powered vehicles, they may prove to be almost as disappointing as fuel cells.

The best available lithium batteries can store about 200 watt-hours per kilogram.[19] The energy density of both gasoline and diesel fuel is about 12,500 Wh/kg. Thus, even if electric motors are five times as efficient as ICEs (a typical value), and batteries were to improve by a factor of three (which may be a dream), there would still be more than a four-to-one difference in effective energy storage. This translates in into limited ranges for battery-electric vehicles. Limited ranges and batteries' intrinsic high costs present challenges to widespread deployment of battery-electric vehicles. A lesser factor is the energy loss during battery charging, operation, and discharging. Such losses are much lower than the above-noted losses in fuel-cell systems, but they provide a further disadvantage in comparison to powering vehicles from the grid while in motion.

[18] Figure 7 has been inspired by chart in Bossel, U, Alternative energy conversion. Presentation at FORUM 2008, world Academy of Ceramics, Chianciano, Italy, June 2008, at http://www.efcf.com/reports.

[19] See, for example, Slide 3 of a presentation by Anne de Guibert of SAFT Groupe SA, Batteries and supercapacitor cells for the fully electric vehicle, at the Smart Systems Integration Conference, Brussels, June 2009, at http://www.smart-systems-integration.org/public/electric-vehicle/battery-workshop-documents/presentations/Anne per cent20de per cent20Guibert per cent20Saft.pdf/download.

Nevertheless, powering from batteries will play important roles in a transition to electric traction. Battery vehicles could be preferred for vehicles that make only infrequent short trips. Battery powering could be an adjunct to powering from the grid. For example, Vancouver's new trolley buses can operate for several hundred metres on battery power alone. For many grid-connected vehicles, battery power for the first and last few kilometres of a trip, and during grid failure, could be an essential feature.

Most electric traction today involves powering from the grid while in motion. Five of Canada's six largest cities have electric transit powered from the grid (Ottawa is the exception). Considering these five cities together, most transit journeys are made by electric traction.

Replacing diesel buses with trolley buses is the most cost-effective way of electrifying transit. Indeed, if daily distances travelled per bus are above about 150 kilometres, trolley buses are already cheaper than diesel buses.[20] Trolley buses can provide most of the advantages of electric streetcars (also known as light-rail transit) for a fraction of the cost.[21]

Trucks too can have grid-connected electric traction. Trolley trucks are used, for example, in the Canadian-owned Goldstrike mine in Nevada. A classic use of trolley trucks was in the Québec Cartier iron ore mine at Lac Jeannine, from 1970 until the mine was worked out in 1977. These trucks had electric motors powered from overhead wires. A diesel generator provided the electricity. The reported result of switching from diesel traction to electric traction was an 87-per-cent decrease in fuel consumption and a 23-per-cent increase in productivity.[22] According to Gilbert and Perl,[23]

> The iron ore mine example illustrates a profoundly important point. When there are heavy loads, hill climbing or frequent starts and stops, using a fuel to generate electricity that powers a vehicle's electric motor from a grid can be more efficient than using the fuel to power a vehicle's ICE.

If the overhead wires at the Lac Jeannine mine had been connected to Hydro-Québec's grid, the trolley trucks would have been powered renewably and even more efficiently.

A major challenge for the next few decades is that of applying the efficiency and sustainability of grid-connected electric traction to the comfort and convenience of the personal automobile. This has been

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[20] Capital costs are higher, but operating costs are lower. See Gilbert R, Perl A, *Transport Revolutions: Moving People and Freight without Oil*. Second Edition. New Society Publishers, Gabriola Island, B.C, 2010.

[21] The approximate capital cost of Toronto's proposed light-rail system (Transit City), including vehicles, is about $70 million per kilometre, not including a 10-km tunnelled portion, which is to cost $300 million/km. A trolley bus system, including vehicles sufficient to maintain a 10-minute or better headway, appears to cost well under $2 million/km. (See Andersson PG, Trolleybus Landskrona: the world's smallest trolleybus system. Presentation at the First International Workshop to Push Forward your Trolley Bus System, Salzburg, Austria, 2006, at http://www.trolleymotion.com/common/files/uitp/Anderson_Landskrona.pdf. The latter estimate does not include the cost of the roadway, which often already exists and can be shared, and might typically be valued at about $2 million per lane-kilometre.

[22] See '1970–1977 — Quebec Cartier Mine, Canada,' Trolley History, Hutnyak Consulting, Elko, NV, 2001, at http://www.hutnyak.com/Trolley/trolleyhistory.html#QCM.

[23] The quotation is from Page 156 of the source detailed in Note 20.

attempted for several decades, usually under the rubric Personal Rapid Transport.[24] PRT systems comprise fully automated, one- to six-person vehicles (pods) on reserved guideways providing direct origin-to-destination service on demand. Barriers to deployment of PRT have included the widespread availability of low-cost gasoline and, perhaps even more importantly, the inadequacy of the electronic control systems necessary for safe, reliable operation. Theses barrier appear to be dissolving.

The first commercial PRT application is to come into operation at Heathrow Airport in London, UK, initially linking two parking areas and a passenger terminal, illustrated in Figure 8.[25]

Figure 8 goes about here

Similar systems are mooted for Masdar City Abu Dhabi, and for the airport at St. Louis, Missouri.[26] These systems have pods *on* their guideways. An alternative method, with pods *below* their guideways is illustrated in Figure 9,[27] and also in the four-minute video 'Bubbles and Beams: A Convenient Future.'[28] Suspending pods below guideways could provide better weather protection and have other advantages, although pods on guideways is more similar to how most land transport systems function. Pods on guideways may thus be more acceptable, at least initially.

Figure 9 goes about here

At the end of the 'Bubbles and Beams' video is an illustration of a dual-mode concept. Pods sprout wheels and can be driven away from the guideway. (In single-mode PRT concepts, pods are always on or hung from guideways and are always under the control of the PRT system.) Dual-mode PRT systems have features in common with electric vehicles such as the trolley buses discussed above, which are normally attached to the grid via overhead wires but can be driven away from the wires.

[24] For an advocate's view of the history of PRT, see Anderson JE, *The future of high-capacity personal rapid transit*, Presentation at the Advanced Automated Transit Systems Conference, Bologna, Italy, November 7–8, 2005, http://www.gettherefast.org/documents/FutureofHCPRT-Jan606.doc. For what may be a more balanced view, see Cottrell, WD, Critical review of the personal rapid transit literature, *Proceedings of the 10th International Conference on Automated People Movers*, Orlando, FL, 1-4 May 2005, American Society of Civil Engineers, Washington DC.

[25] Figure 8 is from the Web site of ULTra PRT Ltd, the company that developed and is installing the system at Heathrow Airport, at http://www.ultraprt.com/media/pictures/press-images/.

[26] For the Masdar City proposal, see http://www.treehugger.com/files/2009/02/masdar-prt-interview.php. For the St. Louis proposal, see http://www.ultraprt.com/cms/index.php?page=st-louis-airport-development.

[27] Figure 9 is from http://a6.unimodal.com/index.php?option=com_frontpage&Itemid=40.

[28] The 'Bubbles and Beams' video was produced for the Swedish Institute for Transportation and Communication Analysis. It is at http://video.google.com/videoplay?docid=-2462675742485310587#. The associated report, A general transport system, is at http://www.sika-institute.se/upload/Publikationer/sr_2006_1_eng_total.pdf.

The states of New Jersey and Virginia have each commissioned major reports favourable to PRT.[29] Table 1 provides estimates from the New Jersey report.[30] It suggests that compared with surface light-rail transit, and certainly with tunnelled LRT, PRT would be cheaper to build and operate, have higher capacity, and provide much better service. Per-passenger-kilometre costs are similar to those for subway systems, *if* the subway systems have the high ridership levels required to make them viable.

Table 1 goes about here

PRT proposals are being discussed for several U.S. communities, including Santa Cruz and Alameda in California, Edina, Minneapolis, Ithaca, New York, and Perimeter Center, Atlanta.[31] Perhaps the strongest community interest is in Winona, Minnesota.[32] The State of Minnesota has issued a request for expressions of interest from parties who have the ability to build, operate, and maintain a PRT system.[33]

Quebec has numerous assets and features relative to the deployment of PRT. They include:

- Much need to reduce oil dependence – as noted above
- Much renewably produced electricity – as noted above
- Much relevant engineering expertise – notably in Hydro-Québec and Bombardier, but also in numerous other businesses and organizations concerned with electric traction and control systems.
- Much suburbia, particularly around Montreal – relevant because the optimal use for PRT may be serving lower-density communities.

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[29] The New Jersey report is Carnegie JA, Hoffman PS, *Viability of Personal Rapid Transit in New Jersey*, report prepared for the New Jersey Department of Transportation and NJ TRANSIT, February 2007, at http://www.njstatelib.org/digit/t764/t7642007z.pdf. The Virginia report is *Viability of Personal Rapid Transit in Virginia*. Report by the Virginia Department of Rail and Public Transportation to the Governor and General Assembly of Virginia, January 2008, at http://leg2.state.va.us/dls/h&sdocs.nsf/By+Year/HD112008/$file/HD11.pdf. A December 2008 update of this report is available at http://faculty.washington.edu/jbs/itrans/VA-DOT per cent20PRT per cent20report-09.pdf.

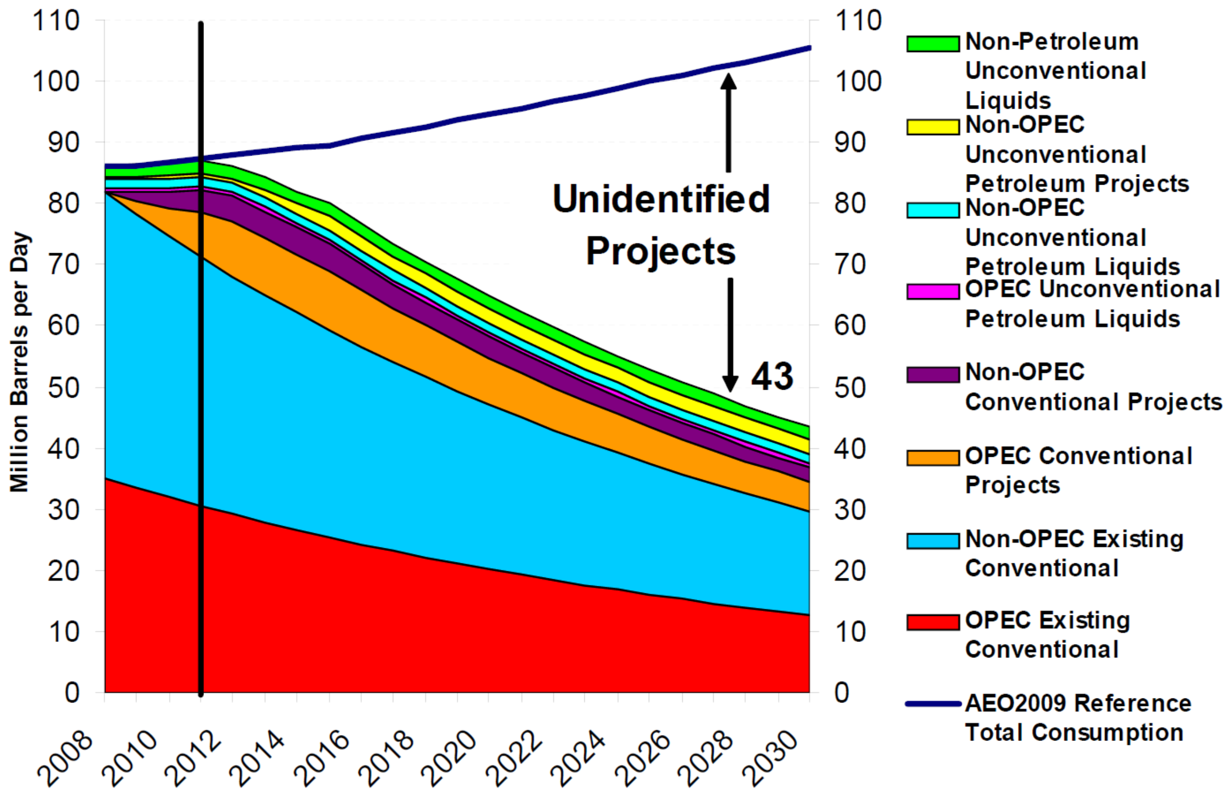
[30] The estimates in Table 1 are mostly from Tables A-2, A-3, A-4, A-6, and A-25 of the first source detailed in Note 29. The estimates of subway and LRT capital costs in the first column are from ongoing implementations in Toronto.

[31] Links to the respective requests for proposals, or other information, are at http://www.ultraprt.com.

[32] See Mark Sommerhauser, Winona officials release details for PRT funding plan, *Winona Daily News*, December 16, 2009, at http://www.winonadailynews.com/news/local/article_83e794d2-ea08-11de-a4d0-001cc4c002e0.html.

[33] Minnesota, Request for Interest: Personal Rapid Transit (PRT) Viability and Benefits (St. Paul, Minnesota: Department of Transportation, 2010), at http://www.dot.state.mn.us/transit/docs/PRT per cent20RFI.pdf.

Figure 1. Recent and projected world oil supply and demand, 2008 to 2031



Note: OPEC refers to the Organization of Petroleum Exporting Countries. AEO2009 refers to the US Energy Information Administration's *Annual Energy Outlook* (2009 edition).

Figure 2. Daily closing price at the New York Mercantile Exchange (NYMEX) for next month's delivery of "light, sweet" crude oil, January 1990 to May 2010

Figure 3. Monthly U.S sales of passenger cars and light-duty trucks (SUVs etc) and average crude oil price, January 2006 to January 2010

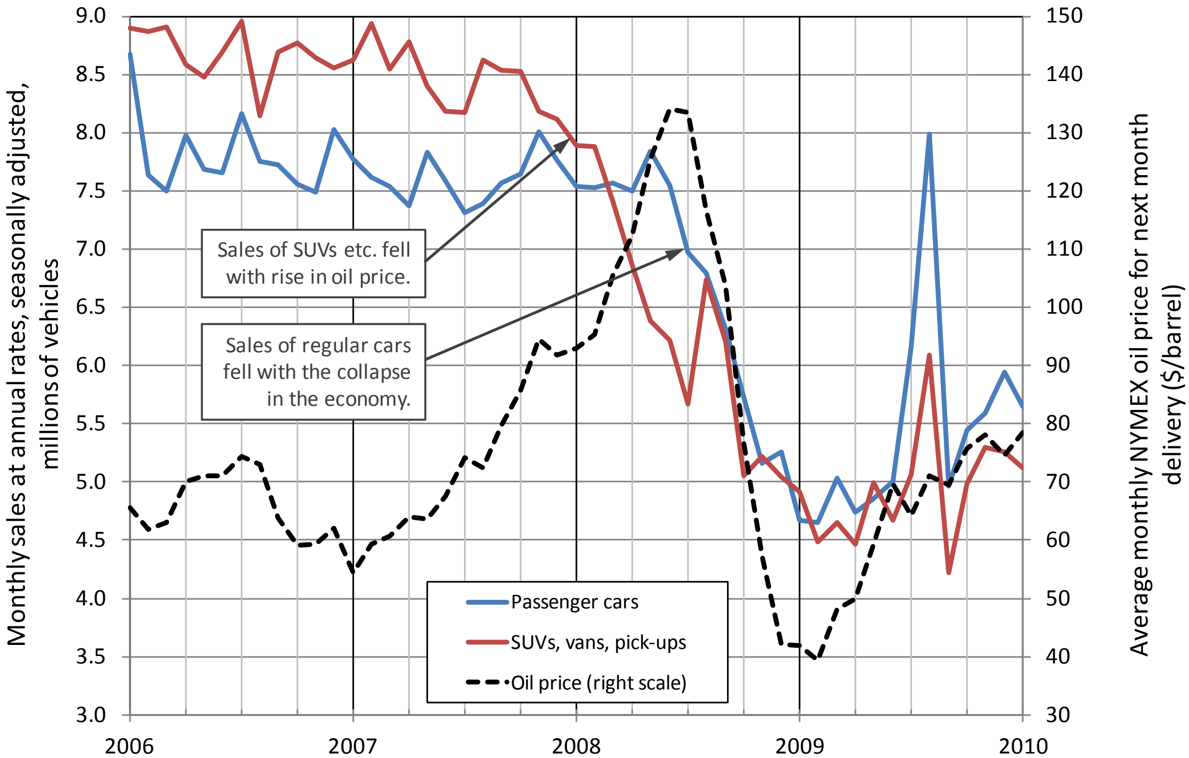


Figure 4. Vehicular travel in the U.S. January 1990 to January 2010

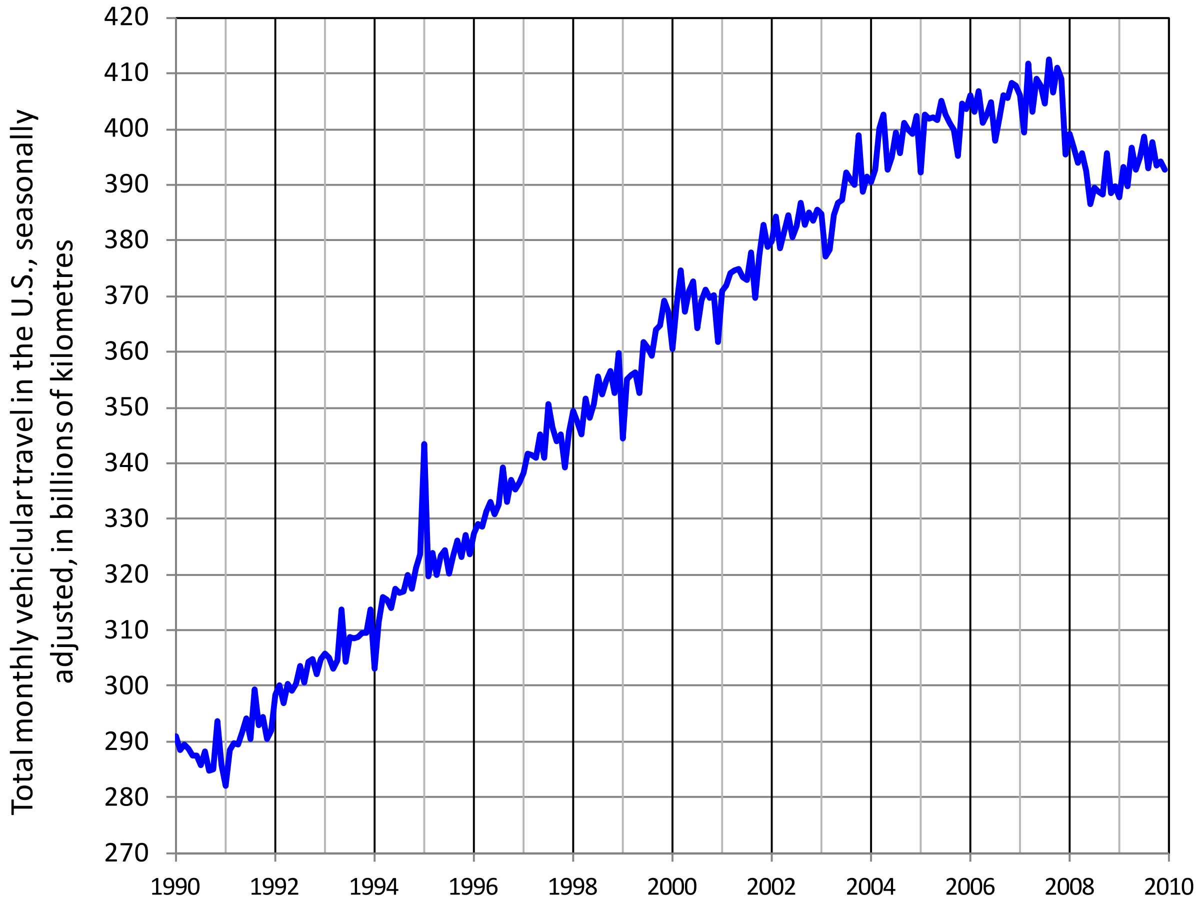


Figure 5. Two mutually reinforcing vicious cycles involving oil prices and economic factors

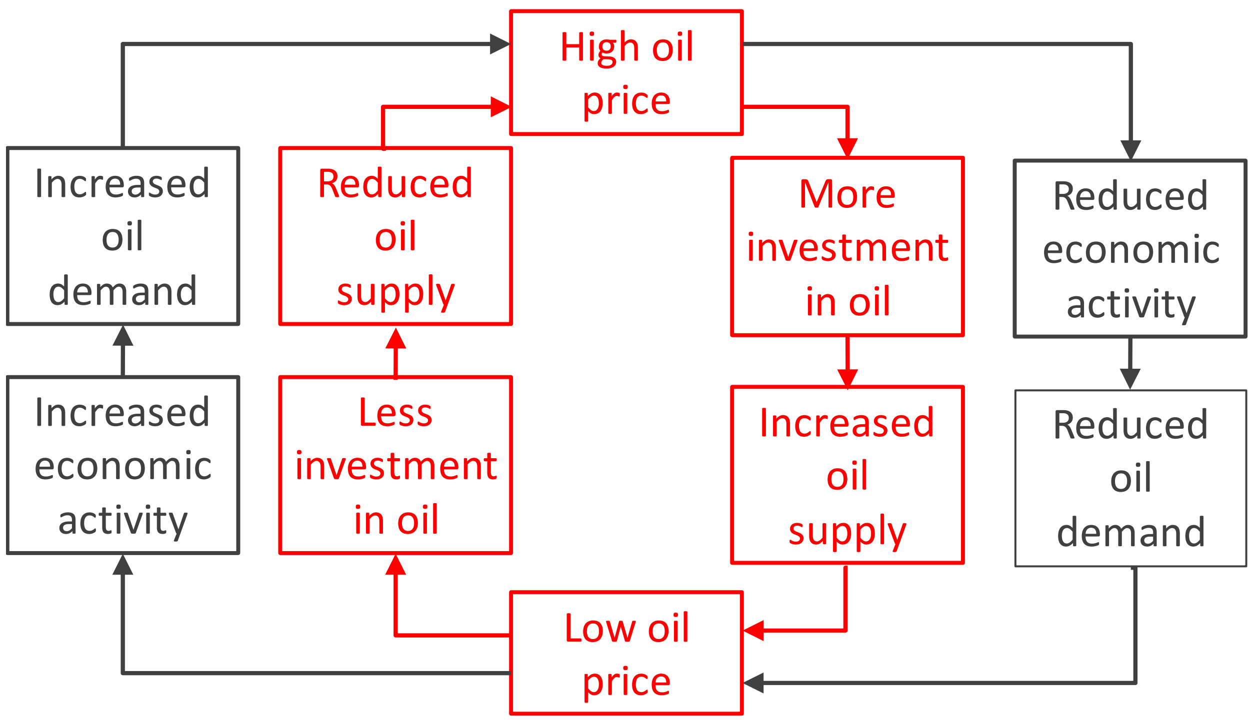
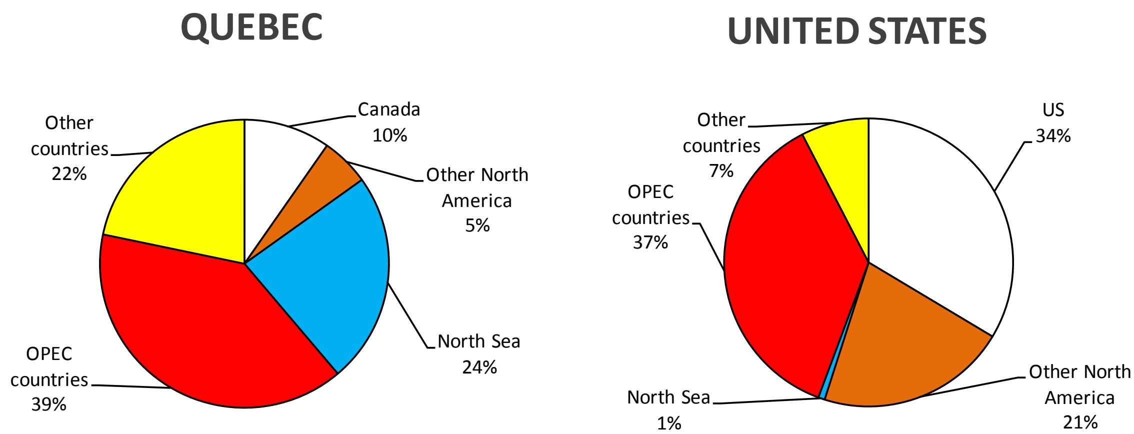


Figure 6. Source of crude oil used in Quebec and the U.S., 2009



	Quebec	US
Reliance on on imports …………………………………………	90%	66%
Reliance on sources outside North America ……………….	85%	45%
Reliance on OPEC countries …………………………………	39%	36%

Figure 7. Comparison of the transfer of traction energy by hydrogen with transfer by electrons

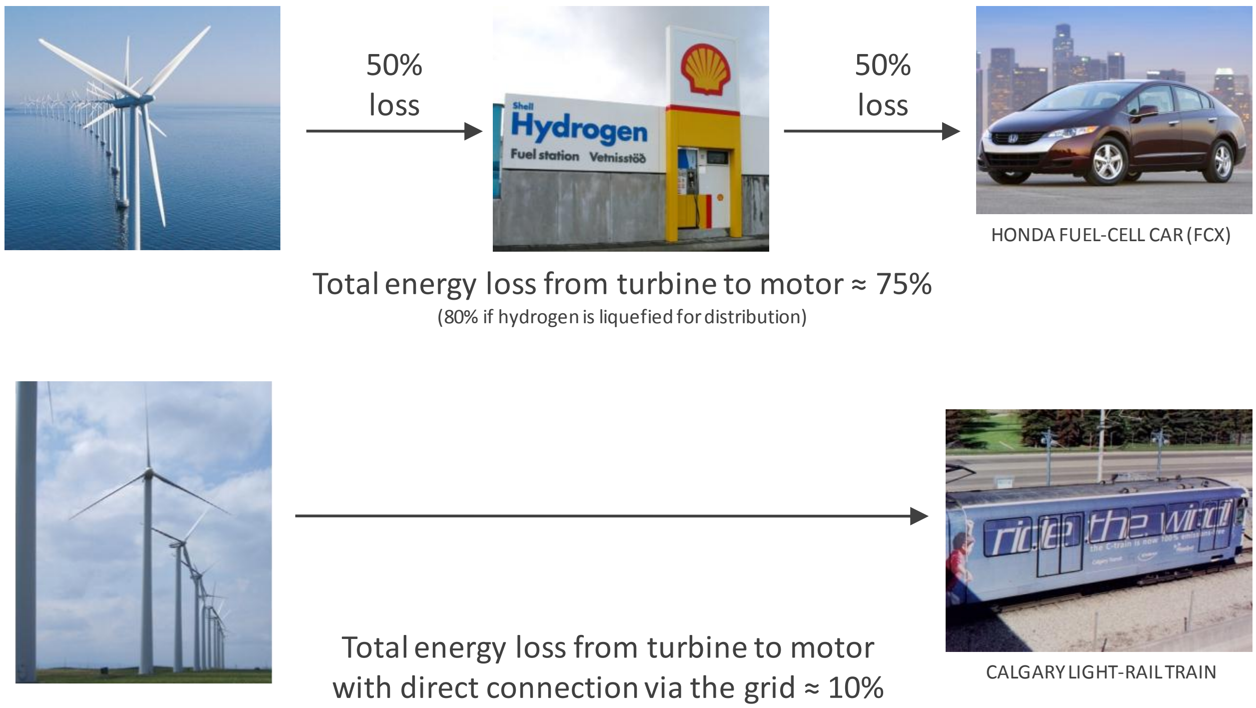


Figure 8. Ultra PRT pods on their guideway at Heathrow Airport

Figure 9. Artist's impression of a possible PRT installation at Seattle, Washington

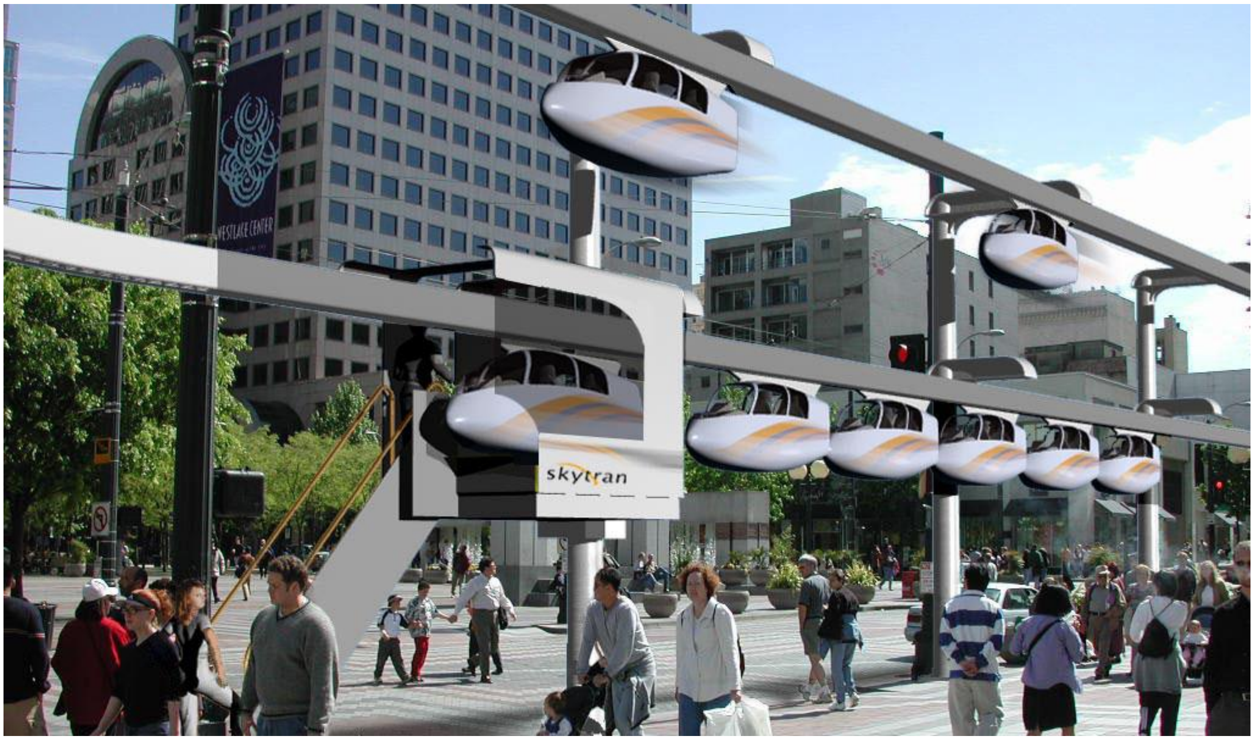


Table 1. Comparison of PRT with light-rail transit (LRT) and subway systems

	Construc-tion cost in $million/km	Time for a 6.4-km direct trip in minutes	Time for a 12.8-km trip, one transfer, in minutes	Average capacity persons/hour/direction	Yearly millions of person-kilometres for each two-way km of service	Capital cost per person-kilometre in dollars	Operating cost per person-kilometre in dollars	Total cost per person-kilometre in dollars	Total cost compared with PRT
Subway	300	15.0	35.0	14,400	189.2	0.10	0.25	0.35	1.05
LRT subway	300	19.0	43.0	3,300	43.4	0.45	0.42	0.87	2.59
LRT surface	69	19.0	43.0	3,300	43.4	0.10	0.42	0.52	1.56
PRT (two-way)	30	11.4	21.9	4,100	53.9	0.04	0.30	0.34	1.00