

Tethered vehicle systems for sustainable cities

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Introduction: The imminence of energy constraints

What should be the main concerns of transport policy makers, in cities and elsewhere?

- Sustainability? Yes. But it means different things to different people, often quite different; bridging the differences can be a huge challenge.
- Kyoto? Yes. But it is hard to persuade Canadians that warmer winters will be a problem, or that they should prevent or prepare for sea-level rise in 2050.
- Energy constraints? Yes. It is hardly on policy makers' radar, but signs of early – perhaps profound – impacts are clear. Energy concerns should be foremost in our policy-making and shape our approaches to sustainability and climate change, and also to land-use and transport planning for urban regions.

The end of cheap oil is in sight and may already be here. After several false alarms, the prospect of major constraints on the availability of transport fuels is becoming more firmly entrenched. A consensus is beginning to emerge that world production of oil could peak during the next decade. The most authoritative perspective is that represented in figure 1 (ALEKETT, 2004). The production peak would echo the peak in worldwide oil discov-

ery, which occurred in the early 1960s, as shown in figure 2 (LONGWELL, 2002).

Meanwhile, demand for transport fuels continues to rise, driven chiefly by growth in economic and transport activity in China and other industrializing countries, resulting in sharply elevated prices. China is now the second largest user of oil, after the United States. Her imports of oil and oil products increased by about 45 percent during 2004 (IEA, 2005).

Almost every aspect of life in industrialized countries depends on the ready availability of low-cost crude oil, whose products fuel 95 percent of transport (IEA, 2004). Notable features of the dependence are sprawling communities and long supply chains. Both will be difficult to change when oil becomes very expensive. The result could be massive economic and social disruption.

Much of the automotive industry and many governments propose that hydrogen used in fuel cells – or even in internal combustion engines (ICEs) – will replace gasoline and diesel oil as transport fuels. This scenario is unlikely. Both hydrogen and fuel cells will be too expensive.

Today, most hydrogen is made from natural gas. Discoveries of natural gas worldwide peaked a decade or so after discoveries of oil peaked (fig. 2). Thus, as world production of oil is expected to peak during the next decade, so might natural gas production peak within two decades. North American production of natural gas – the source of 95 percent of hydrogen produced in the U.S. – appears to have already peaked (SIMMONS, 2003), resulting in large increases in wholesale and retail prices. There is much natural gas in the Middle East, Russia, and elsewhere, but there are major constraints on moving it between continents. An expensive alternative is electrolysis using renewable sources of electricity.

Even with sufficient low-cost hydrogen, fuel cells could well be too expensive, unreliable, and inefficient to permit their penetration as functional equivalents to ICE-powered vehicles. According to a recent analysis, "In spite of substantial R&D spending by the [U.S. Department of Energy] and industry, costs are still a factor of 10 to 20 times too expensive, these fuel cells are short of required durability, and their energy efficiency is still too low for light-duty-vehicle applications. Accordingly, the challenges of developing ... fuel cells for automotive applications are large, and the solutions to overcoming these challenges are uncertain" (U.S. NATIONAL RESEARCH COUNCIL, 2004).

In an energy-constrained world it will make more sense to drive electric motors directly rather than use electricity to produce hydrogen that, via a fuel cell, is used to produce electricity that then drives motors. Thus, land transport systems in the 21st century could be dominated by tethered vehicles, i.e. vehicles that receive their motive energy via a rail, wire or mag-

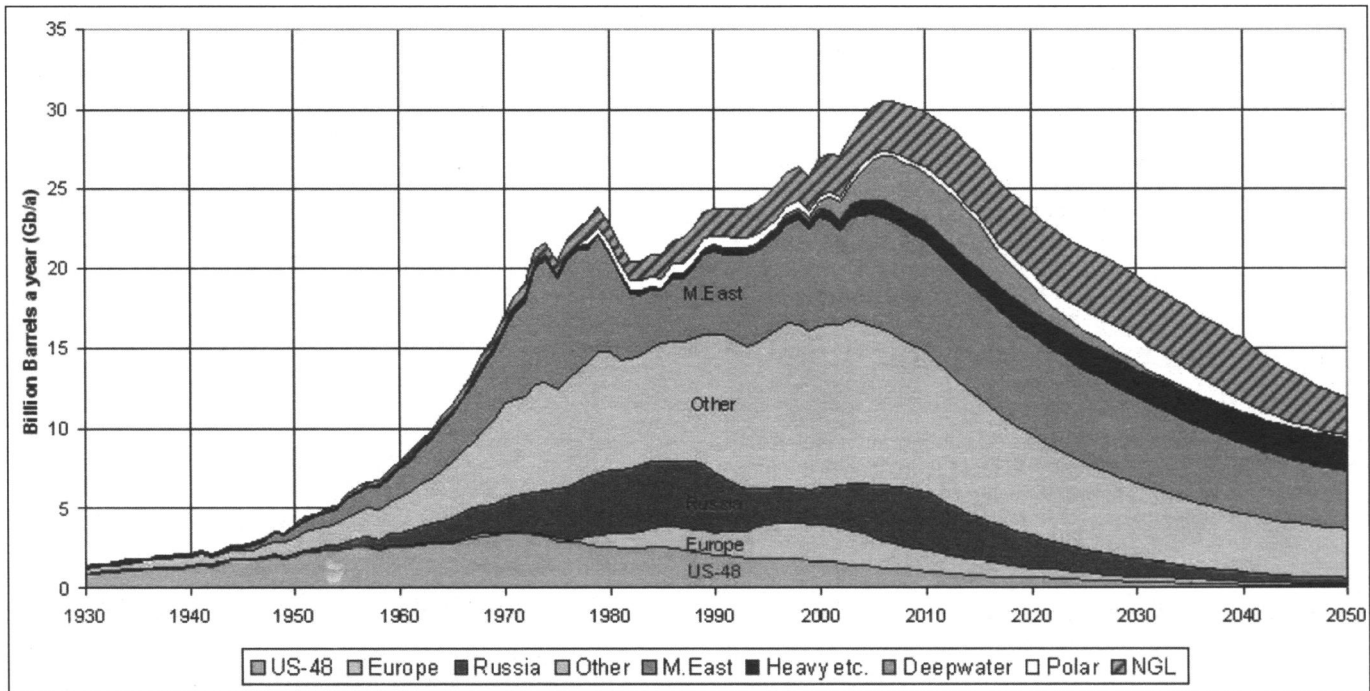


Fig. 1: World production by region of regular oil and natural gas liquids, actual and estimated, billions of barrels per year, 1930-2050.

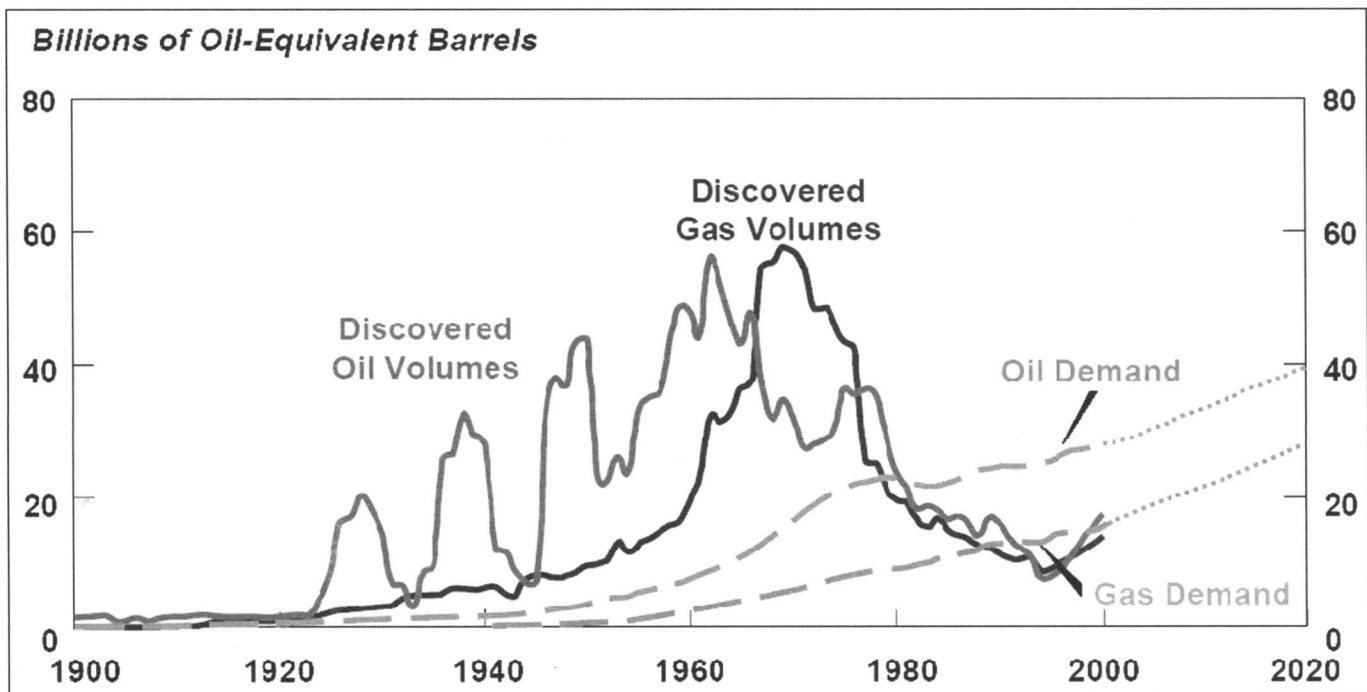


Fig. 2: World discovery of and demand for oil, 1900-2000, and projected potential demand until 2020.

netic effect than from an on-board source such as a gasoline tank or a battery.

Tethered vehicles have four relevant advantages, discussed below:

- they can have remarkably low energy intensities;
- their primary fuels can include a wide range of renewable and non-renewable sources;
- these primary fuels, and their associated electricity generating

systems, can be readily substituted for one other, allowing easy transitions towards use of renewable energy; and,

- for the most part tethered systems involve familiar, tried, tested, and available technology.

Tethered vehicles have two disadvantages, also discussed below:

- they are confined to routes with appropriate infrastructure (e.g. rails and wires); and,

• they rely on continuously available, centrally provided power. In an energy-constrained world that uses as little fossil fuel as possible, the advantages of tethered vehicles will be seen to greatly outweigh the disadvantages. Thus, what is proposed here is that cities think ahead and invest heavily in tethered systems. In the discussion that follows, the focus will be on the transport aspects of tethered systems, but the energy aspects are equally important. A fundamental question is whether sufficient electricity could be sustainably generated to support widespread tethered transport systems as well as provide for current uses. The answer seems to be “yes” (CZISCH, 2004).

Energy use by tethered and other vehicles

The superior performance of tethered passenger vehicles with respect to energy use is illustrated in table 1. In each of the three categories of vehicle, tethered vehicles show lower operational

Table 1
Energy use in megajoules per passenger-kilometer by various modes. Tethered modes are shown in italics

Vehicle type	Source	Fuel	Occupancy (pers./veh.)	Energy use (mJ/pkm)
Personal vehicles:				
SUVs, vans, etc.	A	Gasoline	1.70	3.27
Large cars	A	Gasoline	1.65	2.55
Small cars	A	Gasoline	1.65	2.02
Motorcycles	A	Gasoline	1.10	1.46
Fuel-cell car	B	Hydrogen	1.65	0.92
Hybrid electric car	B	Gasoline	1.65	0.90
Very small car	C	Diesel	1.30	0.89
<i>Personal Rapid Transit</i>	<i>D</i>	<i>Electricity</i>	<i>1.65</i>	<i>0.49</i>
Public transport between cities				
Intercity rail (U.S.)	E	Diesel		2.20
School bus	A	Diesel	19.5	1.02
Intercity bus	A	Diesel	16.8	0.90
<i>Intercity rail (U.S.)</i>	<i>E</i>	<i>Electricity</i>		<i>0.64</i>
Public transport within cities				
Transit bus	F	Diesel	9.3	2.73
<i>Trolleybus</i>	<i>F</i>	<i>Electricity</i>	<i>14.6</i>	<i>0.88</i>
<i>Light rail/streetcar (U.S.)</i>	<i>F</i>	<i>Electricity</i>	<i>26.5</i>	<i>0.76</i>
<i>Heavy rail (U.S.)</i>	<i>F</i>	<i>Electricity</i>		<i>0.58</i>
Sources: A: Natural Resources Canada (2004) B: U.S. Department of Energy (2004) C: Transport Canada (2003) D: Author's average of several estimates E: Author's average of several estimates F: APTA (2004)				

energy use.

Overall (primary) energy use can be much greater than operational (secondary) energy use, according to how the energy is supplied. For example, electricity produced by a combined-cycle gas turbine generator requires expenditure of about 90 percent more primary energy in the form of generator fuel as is available in the secondary energy in the electricity (WEI, 2002). Similarly, if hydrogen for a fuel cell is produced by electrolysis, the energy content of the electricity used is about 60 percent higher than the energy content of the hydrogen produced (U.S. NATIONAL RESEARCH COUNCIL, 2004).

With such conversion losses, it is important to consider the primary energy use; this is a better indicator of the energy bur-

den. However, when the secondary energy – which provides the motive power – can be produced with little intermediate conversion, considerations of primary energy use are less important. Examples of low conversion losses are gasoline produced from conventional oil and electricity from wind turbines.

The ability of tethered vehicles to use renewable energy is illustrated in figure 3, which shows one of Calgary's light-rail trains, running with the slogan “Ride the Wind.” The slogan is justified by Calgary Transit's annual purchase of 26 gigawatt-hours of electricity from a wind farm, equivalent to 100 percent



Fig. 3: Calgary's LRT system is fuelled by wind energy.

of the light-rail system's consumption.

Tethered vehicles can also provide superior performance in freight transport. There are no tethered electric freight trains in

Table 2
Energy use by freight transport in Finland, in megajoules per tonne-kilometer

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

Source:
G: O.Andersen et al. (1999)

North America. The comparison in table 2 is for Finland. Not shown in figure 2 are tethered versions of trucks, known as “trolley trucks,” which like trolleybuses are powered through an overhead wire. They are used extensively in mining and other off-road operations (fig. 4). Data on the comparative energy use of trolley trucks and regular trucks are not available. The difference between the two is likely comparable to that shown in table 2 for diesel and electric trains.

The particular features of electric motors that make them more efficient than comparable internal-combustion engines are:

- higher torque at low speeds, thus requiring less fuel use and a smaller engine;
- smaller engines mean less weight to carry, also meaning less fuel use; and,
- electric drive systems can have regenerative braking – motive energy is captured when decelerating rather than lost as friction heat – again resulting in energy savings. As well, tethered

vehicles do not need energy to carry their fuel. The low energy intensities of tethered vehicles, for passengers and freight, suggest that extensive use of them should be considered as part of the preparation for an era of energy constraints.



Fig. 4: Trolley truck operating at the Quebec Cartier iron ore mine, Lac Jeannine, 1970s.

Tethered vehicles can use a variety of primary energy sources

Almost as important for sustainability as tethered vehicles' low energy intensity is their versatility in the use of primary energy sources. Any means of generating electricity for the grid can be a source of energy for tethered vehicle operations. Wind, sun (thermal and photoelectric), tide, falling water, nuclear fission, and combustion of fossil fuels and biofuels can all be energy sources for tethered vehicles.

As we move towards an energy future whose only certainty may be reduced reliance on fossil fuels, the ability to power transport by a wide variety of sources will be advantageous. Moreover, electricity is the most convenient energy currency of many sustainable primary sources, including wind, sun (photoelectric), tide, and falling water.

Tethered vehicle technology is readily available

Tethered electric vehicles have been in practical use for at least 120 years. There were streetcars on Canadian streets before there were automobiles. There has been continuous development of the technology as adoption of these modes has spread throughout the world, and as technical requirements have been enhanced (e.g. for high-speed trains).

Building on well-established technology, there are many opportunities for further enhancement, especially in the matter of personal rapid transit (PRT, noted in table 1). Because PRT could provide a convenient, affordable alternative to automobile use in low-density areas, it offers the opportunity to address what may be the most intractable of transport challenges. A PRT system could even provide for individual ownership of automobiles equipped to spend most journeys in tethered mode but the first

and last few kilometers of each trip in battery mode. Provision for such dual-mode operation may be an unnecessary sophistication in places where automobile ownership is not widespread.

Another major challenge concerns road freight transport, the fastest growing source of energy use and greenhouse gas emissions in most countries. It is possible to conceive of technological development that would allow any truck, and even any road vehicle, to draw motive power from overhead wires, replacing some of it during braking.

Tethered vehicles are restricted to powered routes

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

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

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

Tethered vehicles require continuously available, centrally provided power

Toronto's streetcars and subway trains stopped during the major blackout that affected eastern North America on August 14, 2003, but cars and trucks kept moving, at least for a time. Then they were stopped in traffic jams caused by non-functioning traffic signals and by line-ups at non-functioning gas stations.

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

Greater dependence on tethered transport systems would stimulate designs for greater resilience involving more distributed production and greater redundancy. These would, in any case, be likely features of a more sustainable system of energy supply. Greater resilience for individual vehicles would require weighty battery or other storage, incurring an energy cost that might not be justified for regular use in an energy-constrained world.

Conclusion

The most feasible sustainable alternative to fossil-fuel derived transport fuels would appear to be electricity generated by renewable means. The most energy-efficient method of delivering this energy to moving vehicles is continuously through a teth-

er that carries it to electric motors from a rail or overhead wire. Alternative systems of sustainable transport promise to be less feasible and much more costly.

Energy constraints are already evident. The era of cheap oil, which fuels almost all transport, will likely end during the next decade. Preparation for an era of energy constraints, particularly in respect of transport fuel, is a matter of urgency.

Cities will be sustainable to the extent that their residents can travel within and between them, and can produce and receive essential goods and services, all with little or cumulative impact or irreplaceable resource depletion. Tethered systems address both parts of this requirement. They can provide the functionality and the low impacts that are essential components of sustainable transport.

Cities will not survive without functional transport. Tethered vehicles offer high functionality with low energy consumption. Widespread deployment of tethered systems may be the only preparation for imminent energy constraints that can ensure the survival of cities that is one prerequisite for their sustainability.

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