

Transportation Choices for a Warming Planet

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Introduction

Recent issues of *Innovation* have included articles on energy systems¹ and energy carriers², clean transportation options³, and approaches to dealing with greenhouse gases (GHGs)⁴. In this article we develop this theme by examining the difficult questions of *how* energy and transportation options should be selected, and *who* makes the choices. These are questions that require us to look critically at energy and transportation policy.

To date, the response to climate change has largely relied on information and volunteerism that aim to change individual lifestyle and purchasing choices, which has had little impact in reducing GHGs. Exciting new technologies such as hydrogen fuel cells and hybrid-electric vehicles have been promoted as holding great promise for GHG reductions, but they have not yet transformed our energy system into a sustainable one. It is now clear that coordinated action is needed at the societal level. The public can have the biggest impact on climate change through its support for (or opposition to) the regional, national and international policies made by governments at all levels.

Although climate change is not the only issue arising from transportation (and, more generally, our energy system), it may be one of the most difficult to address. This is because any adverse impacts are perceived to affect future generations and people in other parts of the globe, rather than us in the here and now. Our individual energy-using actions are distributed among 6.6 billion other people, and hidden as “embedded energy” in the products and foods we import into our homes. Furthermore, energy policy and infrastructure are politically fraught topics, so it is not surprising that we have had trouble reaching consensus in Canada on how to tackle rising GHG emissions⁵.

GHGs from transportation are especially difficult to tackle because the vehicular sources are numerous and mobile, as compared to large point sources like industry or power-generation plants. The transportation system affects not only the energy system and GHG emissions, but also completely different issues such as local air quality, traffic congestion, accidents, personal mobility, and social equity⁶.

In this article, we demonstrate that an effective, efficient and equitable means of tackling climate change is to put a price on GHG emissions. In essence, a successful carbon-pricing strategy will ensure that there is a direct material cost for pollution of the atmosphere

¹ Robert L Evans, “Can We Make Our Energy Future More Sustainable?” *Innovation* vol.11, no.6, p.26-30 (November/December) 2007.

² Robert Millar, “Standing on the Summit of Hubbert’s Peak?” *Innovation* vol.11, no.3, p.23-24 (May/June) 2007; and, Hamid Tamehi and Colin Armstrong, “Local Source of Waste Hydrogen Sows the Seeds of the Hydrogen Economy in BC”, *Innovation* vol.12, no.2, p.26-29 (March/April) 2008.

³ Sid Tafler, “Hydrogen Fuels High Hopes for Clean Energy Bus Fleet” *Innovation* vol.12, no.4, p.31-34 (July/August) 2008.

⁴ Peter K Krahn, “Intensity Units: An Effective Approach to Regulate Greenhouse Gas Emissions”, *Innovation* vol.12, no.1, p.28-32 (January/February) 2008; and, Peter Caulfield, “Carbon Capture and Storage: Sequestration Employed to Reduce Greenhouse Gas Emissions”, *Innovation* vol.12, no.3, p.18-21 (May/June) 2008.

⁵ For a insightful commentary on Canada’s political response to climate change, see: “Hot Air: Meeting Canada’s Climate Change Challenge” by Jeffrey Simpson, Mark Jaccard and Nic Rivers (New York: Random House, Inc.), 2007.

⁶ Eric Mazzi and Conor Reynolds, “The big four - assessing the impacts of green vehicles”, Op-Ed in Vancouver Sun, November 19th 2007. Available at: <http://www.canada.com/vancouvernews/editorial/story.html?id=9e3b279f-d397-40d5-8593-9e30e8382c7f&p=1>

Transportation in the Global Energy System

Globally, people use primary energy at a rate of over 2,100 Watts per capita⁷, most of it derived from fossil fuels. An average Canadian uses energy at roughly four times the global average rate.

Energy consumption is closely related to GHG emissions derived from human activity (shown by sector in Figure 1). Transportation does *not* dominate global emissions, which means that policy-makers must be careful not to increase emissions in other sectors when tackling transportation emissions. For example, hydrogen is an energy carrier that takes energy to produce, and, if coal was used to produce it, using hydrogen could cause increased GHGs. Nonetheless, light-duty vehicles (cars, SUVs and small trucks) account for over 10% of the global primary energy demand. In the US and Canada, ground transportation contributes a much larger fraction of emissions.

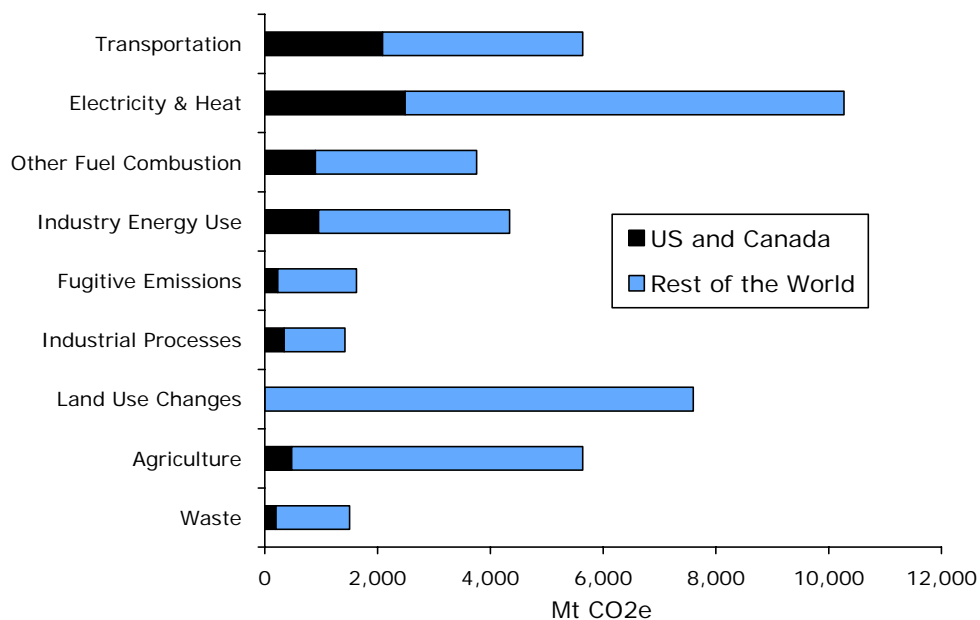


Figure 1 Greenhouse Gas emissions (in megatonnes of carbon dioxide-equivalent emissions) by sector for US+Canada and the rest of the world, using 2003 data (full length of bars show total global emissions for each sector)⁸.

Actions that Reduce Transportation Emissions

The impact of human activity on the environment is linked to population, per-capita consumption, and technology. A simple way of describing the factors contributing to GHG emissions from vehicles is to use the equation $E = N * D * SE * C$, where for a particular country and time interval: E is the total

⁷ This is roughly 23 times the caloric intake from food for a person with a typical 90 W metabolic rate. Another way of looking at this is that it would be impossible to provide all of this energy from biofuels, as our agricultural system could not be scaled up to this extent. Note that: Secondary Energy = (Primary Energy) – (Production/Distribution Losses).

⁸ Baumert, K.A., T. Herzog, and J. Pershing, Navigating the Numbers: Greenhouse Gas Data and International Climate Policy. 2005, World Resources Institute: Washington, DC. Available at: <http://www.wri.org/publication/navigating-the-numbers>

emission of GHG in CO₂ equivalents; N is the number of people; D is the distance traveled per person (km); SE is the amount of secondary energy (eg, gasoline) used per person-kilometer traveled (l/km); and C is the lifecycle GHG emission per unit of vehicle fuel (CO₂/l).

Many technical and social issues surround each term in this *ENDSEC* equation, all of which need to be considered when we evaluate potential GHG-reduction policies.

Number of People (N) and Distance Traveled (D)

Population growth (represented by N) directly results in increased consumption of energy services such as transportation, heating, and electricity. It also means increased consumption of food and consumer products (which have the embodied energy). Societies are in fact able to influence population growth through policies that improve education and health care. However, in this article, we focus on the other factors in *ENDSEC*, which are complex and challenging to implement in their own right. The distance traveled per person (D) depends largely on whether people live close to employment and leisure activities. Typically, D is inversely related to urban density, but D will vary widely between individuals within a particular region depending on their needs and wants.

Secondary Energy per Person-Kilometer (SE)

Secondary Energy (SE) is the energy needed to transport one person a distance of one kilometer, and it is affected by vehicle technology and the way we use our vehicles. We can think of SE as fuel consumption, because for our current transport system it primarily takes the form of chemical energy stored in gasoline or diesel fuel, but it could equally refer to electricity stored in the battery of an electric vehicle.

Fuel consumption can be reduced by decreasing vehicle size, but this results in a large change in vehicle functionality. Smaller vehicles may be cheaper to own, operate and park, but they carry less cargo and may be more vulnerable in traffic accidents. Fuel consumption can be reduced by over 30% by using lighter materials, smarter engine controls, better aerodynamics, and other technical improvements such as hybrid electric vehicle technology, but these improved vehicles mean an increased purchase price. Even more dramatic reductions in emissions can be attained (along with some improvements in public health) by bicycling, walking, or using public transit rather than driving. Whether a smaller vehicle (or no vehicle) is “better” depends on how we use the vehicle, how we value risk, and the degree to which engineering design can offset disadvantages of small vehicles.

We can instantly halve our per-passenger fuel consumption without changing vehicle technology by simply doubling the number of people in the vehicle. Carpooling and car-sharing can reduce the capital expended on cars, air pollution and also traffic and parking congestion. However, it means a new set of trade-offs: effort is required to organize the carpool or car-share, and many people cherish the time spent in their private vehicle.

Life-cycle GHG emissions per unit of Secondary Energy (C)

This is a GHG intensity term that refers to the amount of carbon dioxide-equivalent emissions released for every unit of secondary energy produced. Another way of understanding this term is as the carbon content of a transportation fuel. It is commonly perceived that electric or hydrogen vehicles are “zero-emitters.” In reality, even if the secondary energy use itself produces less or no GHGs, the *production* of secondary energy (eg, refining of oil to produce gasoline or electrolysis to produce hydrogen) always results in some GHGs.

Evaluating Actions to Reduce GHG from Transportation

As we have hinted above, there are many ways to reduce GHGs from transportation, but how do they compare? We now quantitatively present a few alternatives compared to our base case, which is a conventional sports utility vehicle (SUV), fuelled by gasoline and carrying a single occupant. Figure 2 shows grams of CO₂ emitted per person per kilometer for a sample of transportation options, as calculated from *SE*⁹C*. Tailpipe (operational) emissions and upstream fuel production emissions are included in the figure.

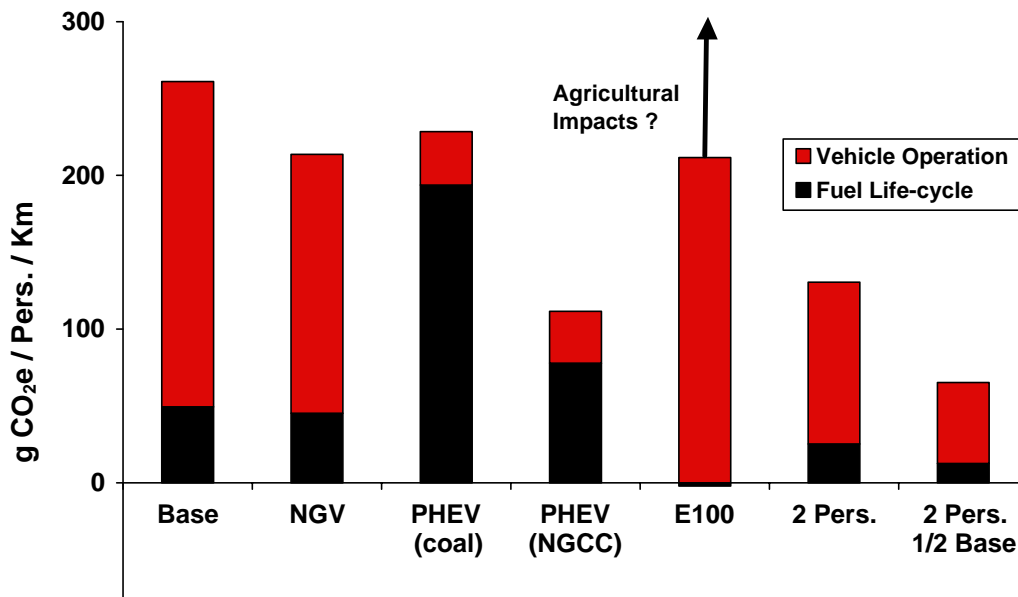


Figure 2 Comparison of specific carbon dioxide equivalent (CO₂e) emissions from a conventional 1,700kg sports utility vehicle, with single occupant (Base) with various alternatives. Plug in hybrid-electric vehicles (PHEVs) are “60% electric” and obtain electricity derived from coal or natural gas. Alternative fuels for the Base vehicle are natural gas (NGV) and 100% ethanol (E100). Higher occupancy (2 pers.), and high occupancy with smaller size (2 Pers., 1/2 Base) are shown by the last bars⁹.

Some gains can be made by powering the vehicle with natural gas, provided that the engine is properly designed for low methane emissions. Two estimates are given for “Plug-in Hybrid-Electric Vehicles” (PHEV), deriving part of their energy from electricity on the grid. If the electric power is derived from efficient natural-gas combined-cycle (NGCC) power plants, total emissions are half that of the base

⁹ Notes for Figure 2:

Base: Conventional gasoline-fuelled single-occupancy SUV

NGV: Modern natural gas powered vehicle

PHEV (coal): Plug-in hybrid single-occupancy electric vehicle (PHEV), electricity grid dominated by coal fired power plant

PHEV (NGCC): PHEV using electricity from a natural gas fired combined-cycle generator.

E100: 100% Ethanol powered vehicle, using average ethanol production methods today, not including agricultural impacts from N₂O and land use change. (Note small negative fuel life-cycle emissions)

2 Per.: Base SUV, but with 2 people per vehicle instead of single occupancy.

2 Pers., 1/2 Base: Double occupancy small car with half the fuel consumption of the Base SUV.

case, but if the electricity comes from conventional coal-fired power plants, the benefits are minimal, (and might even be non-existent if battery and electrical infrastructure life-cycle issues are considered). An important issue to recognize is that plug-in vehicles—if they make up a large part of the fleet—will likely require additional electricity generation beyond that needed for normal residential, commercial and industrial use. Even in BC, a province fortunate to have a large amount of hydro-electricity, the additional “marginal” capacity required might in fact have to be met by building fossil fuel power plants or by importing more electricity generated in such power plants.

Biofuels result in essentially the same CO₂ emissions from vehicle operation (see bar labeled “E100” – for 100% ethanol – in Figure 2), but ideally the crops grown for the fuel would absorb offsetting quantities of CO₂, effectively producing negative upstream emissions. In reality, producing ethanol using current methods requires so much energy that the CO₂ emissions effectively balance the original CO₂ absorption by the feedstock crops. To displace a significant amount of fossil fuels, the world’s agricultural output would have to be expanded several times, resulting in a host of environmental and societal impacts. Agriculture itself is a major source of GHGs (noted in Figure 1). Recent research¹⁰ has shown that switching agricultural land from food to biofuel crops increases GHGs, because land elsewhere must be converted to food-growing, which would dramatically increase lifecycle GHGs, as indicated by the arrow in Figure 2. Cost-effective and environmentally benign biofuels may one day be produced from cellulosic or waste feedstocks, but so far this is not possible in meaningful quantities.

The last two cases in Fig. 2 show the effects of (a) carpooling (ie, two occupants per vehicle rather than only the driver) and (b) carpooling *and* downsizing the vehicle (ie, the effect of using a compact car rather than the SUV considered in the base case). The benefits of carpooling and/or downsizing are larger than for just switching fuels or using alternative fuels or hybrid electric vehicles, but such approaches involve a different set of tradeoffs, such as a reduction in safety, comfort or convenience.

What this means is that the “best” action cannot be chosen on the basis of a single numerical score, even if we can reduce the uncertainties of GHG emissions to zero, because the costs of the actions are qualitatively dissimilar. This is the fundamental challenge we face when choosing policies to encourage the desired actions. Figure 3 illustrates this challenge qualitatively: transportation options differ not only in climate impact (size of red ball), but also in their technical difficulty, demands on individual lifestyle, and non-climate societal impacts. When the different impacts of each option are expounded, it may not be so clear which option is best.

¹⁰ Scharlemann, J.P.W. and W.F. Laurance, *How Green Are Biofuels?* Science, 2008. **319**(5859): p. 43-44.

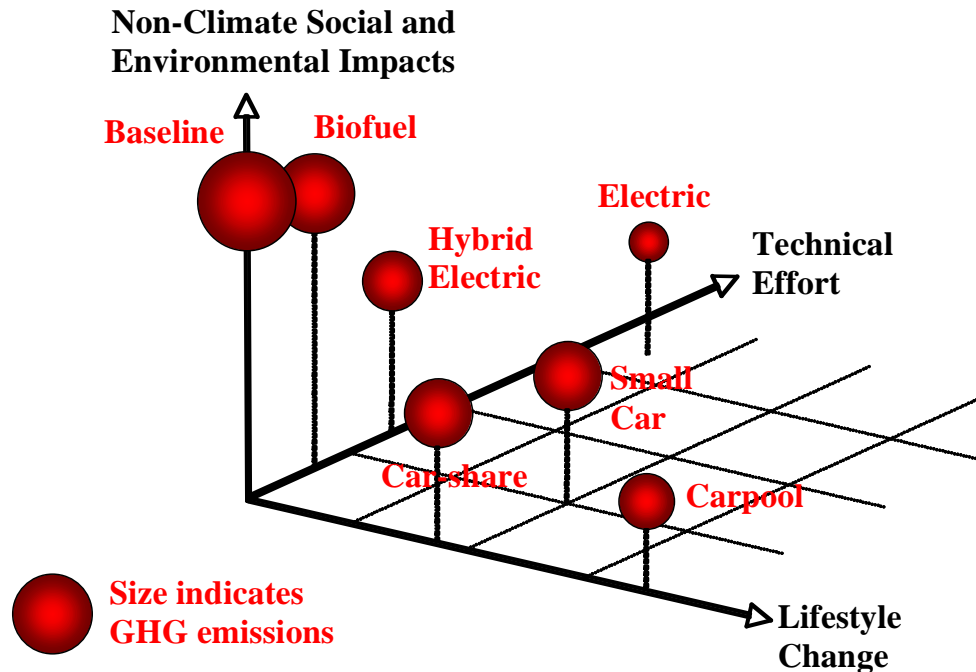


Figure 3 Transportation options evaluated in terms of GHG emissions (size of red ball), technical difficulty, demands on individual lifestyle, and non-climate societal impacts (axes).

Policies to get the right mixture of actions

By acting on any of the terms in *ENDSEC* we can reduce GHG emissions, but it is unrealistic to imagine that we can reduce any individual term to zero. The cost would be too high, not just in terms of money but also environmental impact, political infeasibility and inconvenience. For a given level of effort, it is not obvious what combination of actions would give the greatest GHG reductions, because that optimum will change with future technical innovation, and it will be different for every segment of the population. Faced with this level of complexity, it might be tempting to leave it up to individuals to act after providing them with more information; however information campaigns in Canada and elsewhere have not slowed the rise of GHG emissions.

One option is binding regulations, which could in theory be imposed on each term in *ENDSEC*. However in reality it is politically very difficult to regulate the demand side (ie, Canada's population, or the distance people drive), which leaves all the emphasis on fuel consumption and the carbon-content of the fuel. For example, many governments have imposed regulations on the fraction of biofuels in gasoline or diesel. This is intended to reduce the fuels' effective carbon content (C), but in reality this is an extremely costly way to reduce GHG. Policies promoting electric or hydrogen vehicles face equally complex issues. Policies to improve vehicle fuel efficiency reduce SE , but have the undesirable effect of increasing travel distance D slightly, as people take advantage of lower operating costs (this is known as the rebound effect).

So how can we make a broad impact on GHG emissions without backing the wrong technology, or paying too high a price for an inefficient policy? Most policy experts agree that market-based policies, which effectively put a price on GHG emissions, are likely to be the best way to reduce GHG emissions in a cost-effective manner. Market-based policies inherently take into account local

circumstances and allow adaptation to technical innovation, yet they provide coordinated regional and/or national action. Market-based policies get straight to the root of the problem, and provide an immediate economic incentive for individuals and local governments to find the cheapest way to minimize GHGs from transportation—and indeed from other parts of the energy system. This can be done using a carbon tax or a cap-and-trade system. We discuss the carbon tax in more detail because it was recently recommended for Canada by the National Round Table on the Environment and the Economy (NRTEE), and because British Columbia now has a carbon tax.

A carbon tax can be levied where carbon enters the economy, where it is distributed, or where it is emitted. Every polluting activity in the economy becomes slightly more expensive—which is precisely the point. The energy market will quickly adapt to local conditions to find the most suitable (ie, the cheapest) combination of responses on both the energy supply *and* demand sides. In the transportation sector, as we have seen, there is a whole suite of possible responses to a carbon pricing policy. With other policies, “tax evasion” is possible—an example is by using electric or hydrogen cars even if the electricity or hydrogen production is from polluting fossil-fuel power plants. With a carbon tax, evasion is discouraged by the high cost of GHG emissions levied on these power plants.

There is broad consensus that the carbon price needed to realize significant emission reductions would start at about \$35/tonne (as of mid-October 2008, CO₂ is priced in Europe at around CAD\$35 per tonne). A price of \$100/tonne would increase coal prices by a factor of over 10, but gasoline prices would only rise by a factor of 1.2. At this level of carbon price, one would expect modest changes in vehicle use, but large emission reductions in the electricity sector (the biggest user of coal), possibly paving the way for electric vehicles. It is difficult to know beforehand the “correct” price of carbon tax, so countries with carbon taxes (eg, Sweden, Norway, Finland) have chosen the approach of adjusting the taxes depending on their impact to date. BC’s carbon tax is expected to gradually increase from its current \$10/tonne. The question of affordability is complex, but we estimate that at \$100/tonne CO₂, the carbon tax revenue in Canada could be 5-9% of the GDP—a huge sum, but far lower than the 34% overall taxation rate¹¹. A carbon tax can be made revenue-neutral (as in BC) by shifting a portion of the tax burden from income to emissions.

Carbon taxes and other policy tools may appear to be the domain of economists and bureaucrats, but we believe that engineers and geoscientists can not only understand many of the relevant issues, they can also make important contributions to this field. From design experience, it is obvious that the optimal solution to a problem is usually driven by multiple factors, and should consider local context. It should focus on solving the core problem, rather than preconceived technical solutions. Our training in the physical conservation laws makes it clear that we cannot neglect the “big picture,” exporting our problems to other parts of the energy system. Thus, professional engineers and geoscientists are ideally situated to appreciate the need for pricing mechanisms that encourage better *local* choices without neglecting *global* problems.

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¹¹ This estimate assumes Canadian GDP is \$1550-\$2000 US\$/ton CO₂; taxation rate of 33% from OECD statistical summary (see: <http://stats.oecd.org/wbos/viewhtml.aspx?queryname=459&querytype=view&lang=en>).