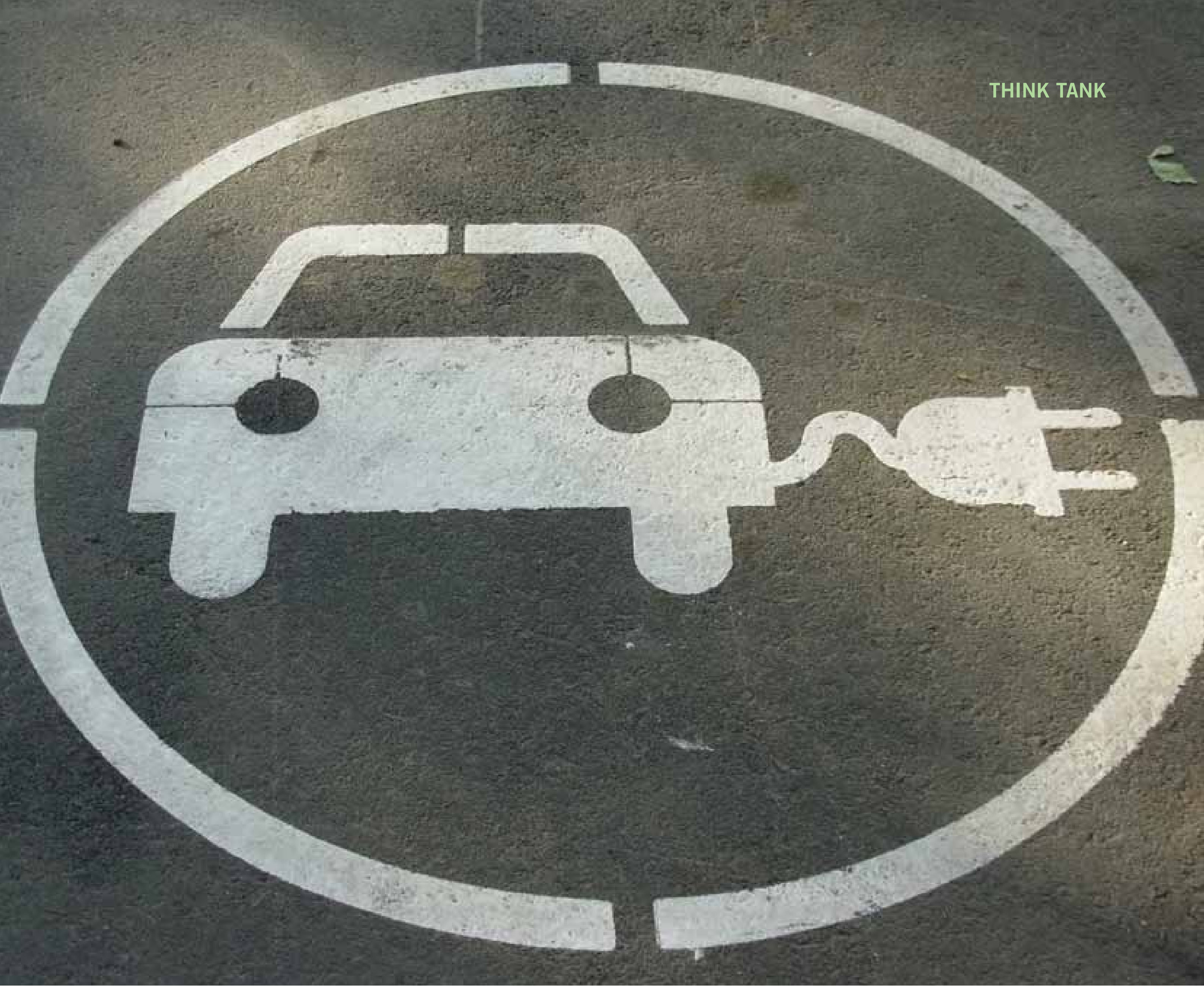

Wind + hybrid vehicles = a match made in renewables heaven?

As alternatives to conventional vehicles, Plug-in Hybrid Electric Vehicles (PHEVs) running off electricity stored in batteries could decrease oil consumption and reduce carbon emissions. And by using electricity derived from clean energy sources, even greater environmental benefits are obtainable. We take a look at the potential benefits arising from the widespread adoption of PHEVs in light of Alberta, Canada's growing interest in wind power.

Plug-in Hybrid Electric Vehicles

In a PHEV, grid electricity stored in a battery pack is the main power source. And in charge depleting/charge sustaining mode (CD/CS) design, the vehicle uses electricity (CD mode) until the battery reaches a certain charging level. At this point, the combustion engine starts up (CS mode).

Controlled charging of PHEVs

The widespread adoption of PHEVs would require a lot of electricity, creating operational issues for Alberta's electrical grid if this increased demand is uncontrolled (e.g., during evenings when most PHEVs would be parked and plugged in). However, if the power required to recharge PHEVs is controlled and shifted to off-peak periods, a large number of PHEVs could be supplied without as much need to expand generation and transmission infrastructure.

With a "smart charging system" in place, when a PHEV is plugged in, the system operator has control over its charging and the PHEV's battery can even be discharged to provide power back to the grid. In such a case, PHEV owners could realize some benefits in return for supplying power to the grid.

Although a smart charging system requires an initial investment in communication infrastructure and incentive plans to encourage owners to participate, it would bring with it several advantages. One is the possibility of employing PHEVs to balance out variations in power output from wind farms. And by pairing PHEVs' needs with wind generation can also produce significant environmental benefits.

Wind generation

In the last five years, the world's total installed capacity in wind power has tripled, rising from 47,600 MW in 2004 to 152,000 MW in 2009. However, due to wind's intermittent nature, regulating the amount of power available to consumers on the grid has proven difficult. Alberta's electricity system currently has an installed capacity of 12,500 MW – 47.56 per cent from coal, 40.56 per cent from gas, 6.96 per cent from hydro and 5.03 per cent from wind.

The number of light vehicles in Alberta is estimated to be 2.5 million, with around 50 per cent being sedans. Estimates of PHEVs' eventual penetration into this market vary from 10 per cent to 50 per cent. When considering the possibility of charging PHEVs at home or work, four different charging scenarios are examined:

1) PHEVs are charged during the day,

2) PHEVs are charged at night,

3) PHEVs are charged over all 24 hours,

4) PHEVs are charged during the night without any control over charging.

With a smart charging system in place, PHEVs' ability to recharge is controlled in the first three scenarios.

The system operator monitors the output from wind farms at all times. If power is available, PHEVs receive a signal telling them to start charging, ensuring that the demand for power matches the available supply. In the fourth scenario, PHEVs begin charging as soon as they get home. If wind farms are unable to meet demand, other power sources take over. The exact mix of usable generating capacity is determined based on the corresponding GSO as mentioned earlier.

It is assumed that all PHEVs are available for charging when not commuting. According to statistical surveys, 16 commuters' departure time can be modeled via a normal distribution. Based on a normal distribution function, the fraction of the vehicles on roads is assumed to be 15 per cent, 35 per cent, 35 per cent and 15 per cent for the hourly commuting blocks from 6:00 to 10:00 in the morning and 16:00 to 20:00 in the evening. An average commuting distance of 40 km for Albertans is based on the Canadian Vehicle Survey 2008.

In the first scenario, vehicles' charging time starts at 8:00 when the first fraction of PHEVs arrives at work and ends at 18:00 when the last fraction leaves work. In the night-time charging scenario, vehicles are charged starting at 17:00 with those fractions that are plugged in at home. The charging period ends at 9:00 the following day when the last fraction of vehicles at home starts commuting. In the 24-hour charging scenario, PHEVs can be charged both at home and at work with the exception of the commuting times described in the beginning of this section.

In the uncontrolled charging scenario, vehicles start charging at 17:00 with those fractions that are plugged in at home, i.e., 35 per cent of PHEVs. For this study, PHEVs are modeled to represent varying per centages of the sedan market, which represents approximately 50 per cent of light vehicles in Canada.17 Emissions were calculated based on the percentage of PHEV sedans and the type of generation used in a particular hour.

The total generating capacity used in each hour is based on the GSO. During the daytime in Alberta there is relatively low availability of wind energy compared to the evening. Therefore, in the daytime only charging scenario PHEVs utilized a small portion of the total wind-based energy (18 per cent for a 10 per cent PHEV market share and 36 per cent for a 50 per cent PHEV market share). During the night-time charging scenario, wind energy usage is between 32 per cent and 63 per cent. The per centages increase to 36 per cent and 89 per cent in the 24-hour charging scenario due to the relatively high availability of PHEVs for charging.

In the uncontrolled charging scenario, PHEVs are all plugged in starting at 20:00 with peak demand reaching 1125 MW, assuming PHEVs capture 50 per cent of the light vehicle market. This peak demand contributed to about 10 per cent of the province's installed generating capacity in 2008. Note that peak demand is limited by the maximum capacity of available electrical outlets. Larger outlet capacity results in higher peak demand. For example, if owners choose 6.6 kW outlets, which correspond to the rating of high-demand appliances such as washers and dryers, peak demand would be as high as 1970 MW, 17 per cent of the province's installed capacity. Since PHEV owners mostly recharge their vehicles at night, a fairly reasonable amount of wind energy, 18 per cent to 33 per cent, can be absorbed.

Let's consider the emissions produced by conventional vehicles versus the extra emissions from PHEVs in the four charging scenarios. The difference between the emissions of conventional vehicles and PHEVs can be interpreted as an overall reduction in emissions arising from cleaner technology used in transportation and generation systems. Generally, emission levels in each scenario are significantly less than in the case of conventional vehicles.

This difference will grow as PHEVs become more popular. In addition, due to the higher availability of wind energy during the night, emissions in the uncontrolled charging scenario will remain relatively close to those of the daytime charging scenario. The lowest emission level is achieved in the 24-hour scenario, which allows the system operator to control PHEV demand at all times.

PHEVs can be used as a controllable storage network to aid in incorporating more wind generation in power systems. Due to a relatively high amount of wind generation in the province, it is impractical to rely solely on PHEVs to soak up all the excess energy. However, a portion of wind generation could be devoted to charging PHEVs. If PHEVs comprise 20 per cent of sedans in Alberta and travel 40 km a day, annual demand for energy would amount to 0.82 TWh. This is approximately half the wind energy produced in Alberta in 2008.

However in some instances the available wind energy might be too high or too low to meet PHEVs' energy requirements. Therefore, wind

power can't be exclusively relied upon for charging PHEVs and the cars themselves can't always absorb the excess capacity produced by wind farms.

On sticker price alone, PHEVs are more expensive than comparable conventional vehicles. However, consumers could still save money over the long term by relying on electricity rather than gasoline for fuel. Governments could also lower PHEV purchase prices via tax breaks and financial incentives to encourage quicker uptake.

The capital cost of a PHEV (the Chevy Volt) is expected to be $41,545 in Canada while the cost of a comparable conventional vehicle in Canada (the Chevy Malibu) is $23,995. With a lifespan of 14 years, and a five per cent annual depreciation rate, the annual premium for a PHEV will be $1,773. However, this doesn't take fuel savings into account. Albertans' average daily commute amounts to 40 km, which translates into 3.285 MWhr annual energy demand by a PHEV.

The average electricity price in Alberta over the last five years is $67.28/MWhr resulting in an annual electricity cost of $222 for a PHEV.

The fuel economy of a Chevy Malibu is 7.9 litres/100 km while the average price of gasoline in Alberta was $0.93/liter in2010. The annual gasoline cost of a comparable conventional sedan is $1073. Therefore, by switching from a conventional vehicle to a PHEV, Albertans could save an additional $851 annually from reduced fuel costs. In total, the relative cost of a PHEV over a conventional sedan can be estimated at $922. The incremental cost of an onboard charger and grid interface is around $200 per vehicle. Spreading the incremental costs out over the expected lifetime of a PHEV amounts to $942 per year with smart charging.

This paper has attempted to investigate PHEVs as a potential investment in light of Alberta's growing wind power capacity, increasingly volatile oil prices and growing pressure to cut CO_2 emissions. Grid operators' ability to control PHEV recharging could help the province to further reduce its emissions and encourage greater use of wind power. In this study, wind generation and PHEVs are paired together.

The reason this study focused on pairing PHEVs and wind generation is because the easy controllability of PHEV charging provides a mechanism to mitigate variations in wind power.

We also presented a cost analysis to show the cost of carbon reduction associated with PHEVs. The cost analysis implies that the reduction in CO_2 emissions attained by pairing wind generation with PHEVs does not justify the expense if PHEVs were to be adopted solely because of government incentives aimed at emission reduction.

The expense is mainly attributable to the higher purchase price of PHEVs compared to similar conventional vehicles.

On the other hand, with automakers' increasing interest in PHEVs, it is likely that the cost of PHEVs will become more competitive with conventional vehicles. Lower capital costs would also encourage more people to buy PHEVs, bringing up the need to control the resulting rise in demand for power. Therefore, policies such as developing smart charging infrastructure to efficiently control that demand or placing extra tariffs on charging during peak times must be created. ■

This feature has been extracted from a study by the School of Public Policy. For more information, please visit: **www.policyschool.ca.**