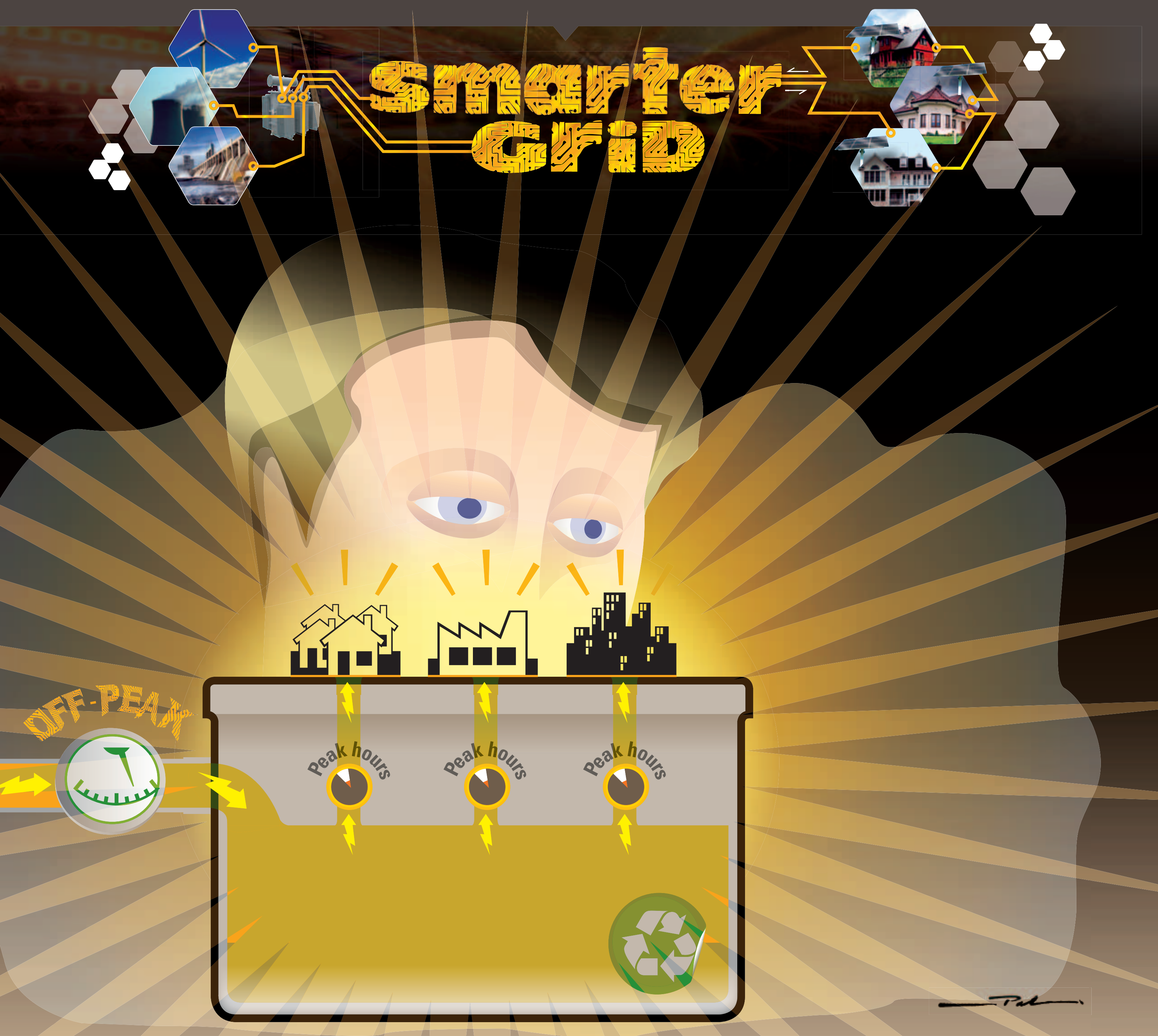

Repurposing Electric Vehicle Batteries for Energy Storage to Support the Smart Grid

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The increasing popularity of electric, hybrid electric vehicles, and plug-in hybrid electric vehicles (EVs, HEVs and PHEVs) is changing the automotive industry and creating a new stream of automotive waste: used EV batteries. Given that they still have approximately 80% of their power capacity after automotive use, it may be feasible to repurpose EV batteries for use in energy storage and peak-shifting. Such repurposed batteries could be employed in a single home, an office building, a factory or a power plant. The integration of these energy storage systems into commercial and domestic applications would help support the efficient operation of the Smart Grid.

An energy storage system of properly configured repurposed Li-ion batteries provides potential cost savings for business and homeowners by shifting electricity purchases to off-peak times. For utilities, such a system can support an integrated system of renewable energy and help regulate demand. At the same time, it can provide environmental benefits, e.g., improved use of renewables and increasing the lifespan of Li-ion batteries. Our research program considers the capacity, degradation and overall performance of repurposed EV batteries, in addition to the development of business and policy strategies for their use in Canada.

Previous vehicle-to-grid (V2G) models [1]-[3] consider using a battery while it is still in the vehicle to return energy to the grid and suggest that PEVs may profitably provide power to the grid/home when vehicles are parked and connected to an electrical outlet [4]-[6]. In these studies, the economic potential of V2G from PEVs is typically considered to provide power for base load and peak load, as well as electric grid services known as ancillary services, considering energy storage of renewable energy sources. However V2G requires complex power electronics and control systems. Most importantly while the battery pack is in the automotive application it is a 'high value' asset and cycling the battery will degrade its performance and shorten its useful life in the vehicle. Alternatively, in a repurposed remanufactured battery system, storage could be online 24 hours a day to provide energy and storage for the Smart Grid, an advantage over V2G, where power from EVs can be accessed only when attached to the grid for charging. Whereas V2G conceives vehicles attached usually during times of lower energy demand, repurposed batteries can function for peak shifting, that is, contribute to the grid times of peak cost and demand.

Similarly the use of new batteries for load shifting has been studied in a number of demonstration projects [7]-[9]. However, the high cost of new Li-ion battery packs makes this option restrictive. Repurposed packs will be available at low cost, making the potential battery energy storage option economical. Incentives may be initially necessary to encourage users of reused battery systems, but are a positive policy measure because of potential environmental benefits. To encourage homeowners to use repurposed EV battery storage systems, decreases in energy transfer fees and a higher payment for feeding into the electrical grid might be considered. Commercial companies have an added incentive for storing power purchased off-peak, because they can benefit directly from unregulated energy prices. Also, note that with energy storage onsite there is a more effective use of the electrical transmission assets which are congested in some zones at peak hours, and there would be less loss of energy through the transmission system.

80%

of original capacity, Li-ion batteries generally have remaining when they are removed from service in vehicles and as such are still useful energy storage systems.

Properly configured batteries could decrease monthly energy costs by shifting electricity purchases to off-peak times and to favour renewable sources.

The benefits of the use of re-purposed packs include cost savings for the end user, more effective use of the transmission grid, emission reductions and integration of renewable power. Because the user can purchase energy during off-peak times, they can take advantage of variable pricing to reduce energy costs. Additionally, using repurposed-packs for energy storage allows for more efficient use of the energy grid by providing constant energy reserves and storage for meeting changes in supply and demand. This can cause a reduction in emissions, for example in Ontario by allowing energy generated using base load nuclear power to be stored and then used instead of coal or natural gas when demand peaks. Finally, using repurposed energy packs for energy storage and peak-shifting makes it easier to integrate intermittent renewable energy such as wind and solar by helping match supply with demand.

A further potential advantage of using repurposed packs is to keep battery packs in service longer, thus making more effective use of the original materials and manufacturing. The effective useful lifespan of 8 years in an EV battery pack is extended by a decade when repurposed for stationary use. Repurposed batteries add a separate life cycle to the manufactured battery and battery management system. When used outside of an EV, batteries have the potential to provide a safe, stable source of energy. Because the battery is first used only to power the EV, the battery is cycled as designed, and performs at optimal efficiency while in the vehicle, increasing

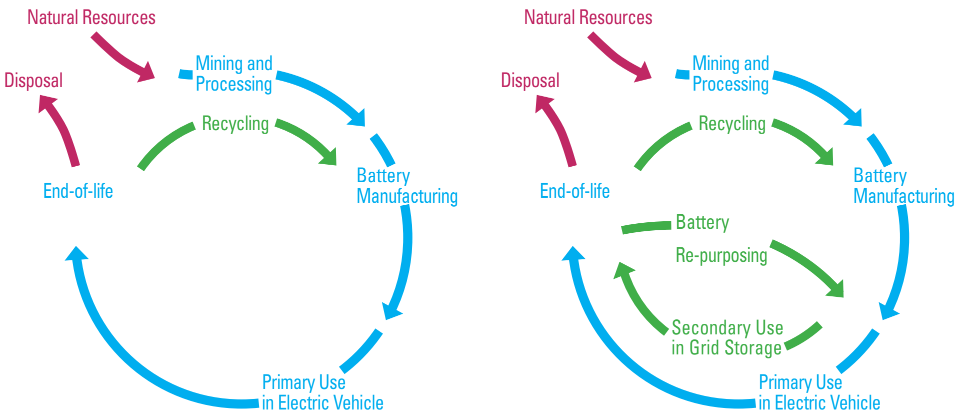

Figure 1. Existing (left) and proposed extended (right) life cycles of EV battery packs [10]

the battery lifespan. Then, the battery is reconfigured to work as a stationary system, repurposed to operate efficiently in a stationary setting. In Figure 1, the process life cycle of repurposing EV batteries for use in stationary settings is shown. Because EV batteries contain a very significant environmental and energy investment in materials and manufacture, it is important to consider the added value provided by extended use in a second life.

Challenges facing the use of repurposed battery packs include energy losses due to 'round-trip' charge efficiency fade, narrow price differentials across times of day in some jurisdictions, the reliability of reused packs and assurance of safety. A key concern with using repurposed batteries for load shifting is that a portion of energy is lost each time a pack is charged and discharged. As a packs ages, the amount of energy lost to heat increases; this is called charge efficiency fade.

For automotive manufacturers, charge efficiency fade has not been a significant concern as in EV operation the total capacity and thus vehicle range are the most important parameters. However, when the packs are being used to store and shift electrical energy, this charge and discharge efficiency critically determines whether energy storage will be cost-effective. Additionally, as energy prices vary geographically and by time of day, the usefulness of repurposed packs for energy storage also varies. There is scant information about the performance of EV battery packs at the end of their life in vehicles. This means that the reliability and future performance of the repurposed packs is also very uncertain.

A key issue facing the use of Li-ion batteries for energy storage is the risk of fire and explosion, so standards will have to be developed. Additionally, recent well-publicized fires in Tesla vehicles and the new Airbus Dreamliner, have brought to the forefront the risk of using Li-ion devices [11], [12]. In large stationary applications which call for greater numbers of battery packs, this risk could be of concern.

Continued research is needed into the technical performance of repurposed EV batteries, in addition to the development of policy strategies for their use in Canada. Future research will develop analytical models using IESO cost data to determine the feasibility of repurposed batteries to provide energy storage and for businesses that purchase unregulated energy.

Most pressingly, analyses of how batteries degrade during their life in EVs are needed to gain a clearer picture of the condition of batteries before they are used to support the Smart Grid. This would allow for better prediction of the performance and lifespan of the repurposed units in repurposed applications. Further, business models must be developed to determine how businesses and residential users can effectively obtain used EV battery systems, and to evaluate how repurposed power products may be marketed in Canada. Finally, there is a need to develop a sound policy strategy in Canada that encourages consumers to purchase the storage units to reduce their energy costs to support the Smart Grid.

References

1. Yilmaz, M. and P.T. Krein, "Review of the Impact of Vehicle-to-Grid Technologies on Distribution Systems and Interface Technologies," IEEE Transactions on Power Electronics Vol. 28(12): 5673-5689, 2013.
2. Kempton, W. and J. Tomic, "Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy," Journal of Power Sources Vol. 144: 280-294, 2005.
3. Peterson, S.B., J. Apt and J.F. Whitacre, "Lithium-ion battery cell degradation resulting from realistic vehicle and vehicle-to-grid utilization," Journal of Power Sources Vol. 195: 2385-2392, 2010.
4. Han, S. and S. Han, "Economic Feasibility of V2G Frequency Regulation in Consideration of Battery Wear," Energies Vol. 6: 748-765, 2013.
5. Mullan, J, D. Harries, T. Braunl and S. Whitely, "The technical, economic and commercial viability of the vehicle-to-grid concept," Energy Policy Vol. 48: 394-406, 2013.
6. Peterson, S.B., J.F. Whitacre and J. Apt, "The economics of using plug-in hybrid electric vehicle battery packs for grid storage," Journal of Power Sources Vol. 195: 2377-2384, 2013.
7. Daud, M.Z., A. Mohamed and M.A. Hannen, "An improved control method of battery energy storage system for hourly dispatch of photovoltaic power sources," Energy Conversion and Management Vol. 73: 256-270, 2013.
8. Gnanamuthu, RM, K. Prasanna, T. Subbaraj, Y.N. Jo and C.W. Lee, "Silver effect of Co–Ni composite material on energy storage and structural behavior for Li-ion batteries," Applied Surface Science Vol. 276: 433-436, 2013.
9. Yoshimoto, K., T. Nanahara and G. Koshimizu, "Analysis of Data Obtained in Demonstration Test about Battery Energy Storage System to Mitigate Output Fluctuation of Wind Farm," Power and Energy Society Conference – Calgary 2009: 1-5, 2009.
10. Ahmadi, L., Yip, M., Fowler, M., Young, S., Fraser, R. Environmental Feasibility of Re-use of Electric Vehicle Batteries. Sustainable Energy and Technology Assessments Vol. 6, 2014: 64-74.
11. BBC Staff. "Boeing Dreamliners: Two JAL flights diverted after glitches," BBC.com. Published October 10th, 2013.
12. T. Cobb. "US Authorities Won't Open Formal Tesla Fire Investigation," HybridCars.com. Published October 25th, 2013. ■

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