Sustainability Issues for Vehicles and Fleet Vehicles Using Hybrid and Assistive Technologies

Lindita Prendi, Simon Che Wen Tseng and Edwin K. L. Tam

Abstract Hybrid electric vehicles (HEVs) are considered preferred alternatives to internal combustion engine vehicles because they can reduce air emissions and fuel consumption while performing competitively against conventional vehicles in commuter usage scenarios. Hybrid vehicle technologies vary widely and offer different advantages and disadvantages from environmental and socio-economic perspectives for passenger vehicles. At the other extreme, fleet vehicles are operated differently from passenger vehicles and idle for about 70 % of their operation time. Hybrid vehicles have yet to be utilized widely by fleets: they would appear to complement fleet operations but there are other approaches to reduce emissions, including assistive technologies to operate in-vehicle equipment and maintain fleet vehicle capabilities instead of idling. Hybrid vehicles and assistive technologies, such as auxiliary power units could offer significant benefits to fleet vehicles by powering electronics while idling and thus reduce the need for conventional engine operation. However, do hybrids and assistive technologies actually provide justifiable benefits in passenger vehicles and fleet vehicles? There are specific end-of-life issues with hybrids and assistive technologies that should be assessed. These issues and the overall sustainability of vehicles can be assessed using life cycle assessment (LCA) approaches.

Keywords Hybrid · Electric · Batteries · Life cycle assessment · Emissions · Fuels · Diesel · Idling · Fleets · Vehicles

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1 Introduction

Mobile sources (cars and trucks) are major contributors to air pollution in metropolitan cities (Calef and Goble 2007). According to Environment Canada (2010) the transportation sector is the largest contributor of GHG emissions in Canada. It has also been reported that transportation sector contributes for one-fourth of GHGs and air pollutants on a global scale (Ogden et al. 2004). With the increase of population the number of vehicles on the road has correspondingly increased. Air pollution from vehicle exhaust is also known to contribute to respiratory system illnesses. Hybrid vehicles are considered a preferred alternative to internal combustion engine vehicles because they are reported to reduce air emissions and fuel consumption while remaining competitive in performance with conventional vehicles in urban or commuter usage scenarios. It has been estimated that "hybrid vehicle sales in the USA exceed 1 million per year by 2012" (ACA 2008). There are a number of variations on hybrid technologies however, ranging from different fuel formulations to different powertrain combinations. The different hybrid configurations can influence how they in turn affect environmental, social, and economic considerations.

At the other extreme of vehicle use, environmental concerns about emissions and rising fuel costs are driving fleet operators (i.e. police, ambulance) to consider alternative technologies for their fleets. Extended fuel consumption and air emissions are attributed to the unique operations of fleet vehicles and in particular, during idling. While drivers of passenger vehicles may have the option of simply not idling, fleet operations, and in particular, emergency vehicle operators, may need to keep the vehicle operating to provide power to operate critical onboard equipment. These demands may be exacerbated during seasonal, temperature extremes. However, prolonged idling can impose significant environmental and economic burdens. Hybrid vehicles might be an attractive solution, but have yet to be utilized widely by fleets. There are other, increasingly mature approaches to reduce emissions, including idling reduction or assistive technologies to operate in-vehicle equipment and maintain fleet vehicle capabilities instead of idling.

This chapter summarizes the state-of-the-art hybrid and assistive technologies for vehicles in general and fleet vehicles, and presents the environmental and socio-economical issues associated with these innovative hybrid and assistive technologies. Substantial research has been conducted on the performance of vehicles using different power trains and energy sources. There is significantly less available research on assistive technologies and life cycle environmental trade-offs for fleet vehicles, especially when considering their unique modes of operation and the novel technologies required for operational purposes. The chapter will focus on the following major aspects:

1. The issues, benefits, and impacts from various hybrid vehicle technologies, including variations in terms of fuels and powertrains;
2. Socio-economic effects related to hybrid vehicles; and

3. Idle reduction or assistive technologies and fleet vehicle issues, including end-of-life issues that may have to be considered.

2 Overview of Hybrid Technologies

The term “hybrid vehicle” is popularly thought of as a combination of a gasoline internal combustion engine and an electric motor. However, there are a variety of technologies that can qualify a vehicle as a “hybrid”. “Hybrid as it affects vehicles could be in terms of the fuel used in the internal combustion engine of vehicles (fuel hybridization) or the combination of propulsion power from an internal combustion engine with that produced by electric energy stored in batteries (drivetrain hybridization)” (Momoh and Omoigui 2009). Since its inception, automobiles have been powered by either the internal combustion engine (ICE) or by an electric motor. Electric motors offered an unparalleled quietness in operation and zero tail pipe emissions, but previously lacked the technology to provide the performance demanded by users.

ICEs were simpler in design and with the abundance of inexpensive crude oil at the time, secured its dominance until recently. With the increase in global awareness in the environmental impacts of personal transportation and the rising cost in crude oil, the trend is to move away from ICE and towards electric vehicles (EV). However, the electric vehicle has not yet become a dominant choice partly due to the still developing battery technology. The hybrid electric vehicle (HEV) is now seen as the intermediate step towards the eventual goal of having EVs serve as the primary type of passenger vehicle (Katrasnik 2007).

Fuel hybridization utilizes current fueling infrastructures by using various different fuels and fuel mixtures to enhance ICE combustion. This outcome will increase thermal efficiency and reduce tail pipe emissions and fuel consumption. Drivetrain hybridization incorporates both the ICE and the electric motor (EM) in several configurations to promote steady state engine operation by minimizing transient operation/combustion variations. The increase in mechanical efficiency of the ICE results in lower tail pipe emissions and fuel consumption (Stone 1999). The following section reviews the state-of-the-art technology in both fuel and powertrain hybridization.

2.1 Fuel Hybridization

Fuel hybridization can be performed in several ways:

1. Using alternative fuels in current 4-stroke ICE in two forms:
   a. gaseous—hydrogen, methane (LNG, CNG)
   b. liquid—methanol, ethanol, bio-diesel

2. Using fuel blends that mix different alternative fuels with fossil fuels (e.g., E10).

The alternative fuels reviewed include: hydrogen, propane, methane, methanol, ethanol and bio-diesel. All these fuels are produced from renewable sources to lower the dependence on the traditional fossil fuels. Methane and propane are produced by anaerobic reactions during waste disposal/management systems. (i.e., landfills). Methanol and ethanol are produced by fermentation of starchy crops such as corn. Bio-diesel is produced by chemically reacting lipids with an alcohol, biomass to fuel or most recently algae to fuel reactions (Demirbas and Demirbas 2011). There have been concerns however, that the use of food crops to produce fuel could result in food shortage. As a result, recent developments have moved toward alternative fuel production using non-food crops such as grass, wood, and algae (Kamimura and Sauer 2008).

Replacing fossil fuels with alternative fuels such as methane or ethanol, is not ideal for conventional spark ignition (SI) engines (Pourkhesalian et al. 2010). It has been reported that volumetric and thermal efficiencies are the highest in gasoline fueled ICEs while brake specific fuel consumption (BSFC) is lowest with gasoline. However, there are some benefits in reduced emissions when using alternative fuels instead of gasoline (Pourkhesalian et al. 2010). Currently spark ignition ICE are designed to operate with gasoline, but if a fuel specific ICE design is developed then alternative fuels might be more efficient. The limiting factor for alternative fuel replacement is that current production capabilities cannot mass produce sufficient quantities of alternative fuels to replace gasoline (Pourkhesalian et al. 2010).

For conventional diesel/compression ignition (CI) engines, replacing fossil fuels with alternative fuels (bio-diesel) is more promising than SI engines (Pourkhesalian et al. 2010). For most current CI engines, minor or no modifications are necessary to operate them with bio-diesel. Bio-diesel produces lower emissions of NOx, PM, and CO and come from renewable recourses. However, BSFC is higher compared to regular diesel due to a lower heating value (Lapuerta et al. 2008). Existing infrastructures can deliver and dispense fuel to vehicles with minor to no modification. Similar to SI alternative fuels, the challenge with bio-diesels is that the current production capabilities cannot mass produce sufficient bio-diesel to replace regular diesel supplies.

Gasoline fuel blends are divided into flex fuel engine blends or ethanol blends. Some of the vehicles currently available can operate with gasoline and other alternative fuels such as natural gas (primarily methane). Compressed natural gas (CNG) is usually used to supplement gasoline in fleet vehicles that idle for a long period of time to reduce the tail pipe emissions. This reduction is due to the smaller hydro-carbon (HC) chains with methane compared to gasoline, which is easier for complete combustion. Current pump gasoline has between 10 and 15 % ethanol blended in to increase the octane number (ON) while reducing refinery processes by utilizing the higher ON of methane and its latent heat of evaporation. However, the overall heating value is lower than pure gasoline, which will increase

BSFC. Both fuel blend methods are aimed to promote more efficient combustion to reduce tail pipe emissions while lower the dependence on fossil fuels (Delgado et al. 2007).

Diesel blends are derived by mixing bio-diesel with regular diesel. Overall, the combustion of bio-diesel in CI engines produces lower smoke, PM, CO, and HC compared to regular diesel fuel with the same (if not improved) engine efficiencies. However, with the increase in blend percentage, there is an increase risk of lower durability due to moving parts sticking, injector choking and filters blocking (Fazal et al. 2011). Blends can range from B10 to B20 in current pump diesel up to B80 in experimental engines. Similarly, bio-diesel reduces the tail pipe emission by promoting complete combustion with its inherent oxygen molecules in the fuel. This lowers pyrolysis of the fuel and lowers PM and CO creation. However, there is a slight increase in NOx due to the excess oxygen. Catalytic technologies such as a lean NOx trap (LNT) can capture the excess NOx produced (Stone 1999).

2.2 Drivetrain Hybridization

Drivetrain hybridization utilizes a combined propulsion system from both:

- Chemical (fuel) energy release from an ICE; and
- Electrical energy generated by the ICE mechanical system/EM stored in batteries.

This combination benefits from both propulsion systems' advantages. From the ICE standpoint, the advantages include the superior power density of carbon-based fuel, the simplicity and low cost of design and manufacture, and the ability to use existing infrastructure. From the EM standpoint, the advantages include instantaneous torque and waste energy recovery (regenerative braking). Apart from utilizing advantages of individual systems, the two systems supplement each other and work together synergistically. The ICE on its own suffers from inefficiencies during transient operations, for example during stop and go traffic conditions with frequent acceleration and deceleration. By incorporating an EM into the propulsion system, engine rpm fluctuations can be minimized during acceleration to promote more steady state ICE operations that increase the overall mechanical and volumetric efficiencies. Regenerative braking technology can be implemented to capture the conventionally wasted mechanical energy during braking/deceleration by charging a traction battery on board to be used for acceleration assistance. The instantaneous torque provided by the EM reduces the necessary ICE engine size and can compensate for the lack of torque at the lower rpm of the ICE engine. This further increases the ICE's mechanical efficiency by reducing the parasitic losses inherent to it (for example, due to less rotating mass and mechanical friction). The further implementation of technologies such as integrated starter generator (ISG) and cylinder deactivation enhances the overall propulsion system's efficiency by

Table 1 Types of drivetrain hybridization and typical applications

	Series hybrid	Parallel hybrid	Series–Parallel hybrid
Make	Chevrolet (GM)	Honda	Toyota
System	Two mode hybrid system	Integrated motor assist	Hybrid synergy drive
Model	Volt	Insight/Civic	Prius

minimizing wasted energy inherent to the conventional ICE system (Momoh and Omoigui 2009).

There are many ways to configure drivetrain hybridization. The specific roles of both ICE and EM within the propulsion system determine the type of hybridization implemented and can be categorized into three main groups: (1) series hybrid; (2) parallel hybrid; and (3) series–parallel hybrid (Table 1). Each design has its respective strengths and weaknesses.

2.2.1 Series Hybrid

The role of an ICE engine is not to power the drivetrain directly via conventional crankshaft rotations. Instead, the electric motor uses the electrical energy generated by ICE to power the drivetrain propelling the vehicle. There is no mechanical connection between the ICE and the drivetrain. The instantaneous torque provided by the EM is more efficient than parallel hybrid systems in stop and go traffic conditions. However, this configuration requires separate motor and generator portions, which usually has a lower combined efficiency compared to conventional transmissions that offsets the overall vehicular efficiency (Momoh and Omoigui 2009).

The state-of-the-art of series hybridization in production is the Chevy Volt. The system, known as Range Extender system, uses the ICE solely to charge the traction battery pack and vehicle propulsion is done by the EM. Current research and development (RandD) efforts focus on applications of ‘in-wheel’ motors where an EM is installed at each wheel driven by the battery. This configuration enables variable wheel speeds that essentially provide the functionality of both the all-wheel-drive (AWD) and limited slip differential (LSD) systems without the conventional mechanical systems (Rambaldi et al. 2011).

2.2.2 Parallel Hybrid

Both the ICE and EM are connected to the drivetrain with the EM functioning in a supplementary role. The ICE is the main source of propulsion with assistance from the EM only under heavy loads such as in the case of acceleration. The EM is usually positioned between the ICE and the conventional transmission. According to Schouten et al. (2003) there are five ways to operate the system depending on the power flow desired:

1. Provide power to the wheels with only the ICE;
2. Use only the EM;
3. Use both the ICE and the EM simultaneously;
4. Charge the batteries using part of the ICE power to drive the EM as a generator (the other part of ICE power is used to drive the wheels); and
5. Slow down the vehicle by letting the wheels drive the EM as a generator that provides power to the battery, otherwise known as regenerative braking.

The state-of-the-art of parallel hybridization in production is Honda's Integrated Motor Assist (IMA) system. Depending on driving conditions and driver inputs, the EM can assist the ICE under heavy load as in acceleration, charge the battery while under light loads as in cruising, or charge the battery by regenerative braking. Current research and development efforts are focused on designing better energy management controllers to optimize the operational efficiencies of all the components. These components include the ICE, EM, battery state-of-charge (SoC), EM/generator speed, braking and gear shifting (Schouten et al. 2003).

2.2.3 Series–Parallel Hybrid

This configuration combines series and parallel hybrid systems: both motors can power the drivetrain independently. The combined power output is controlled by a power splitter where 0–100 % of power from either motor can be utilized in any ratio depending on driving conditions (e.g., 50 % ICE and 50 % EM). This system is also known as "power split" hybridization (Schouten et al. 2003).

The state-of-the-art of series–parallel hybridization in production is the Toyota Prius Synergy Drive Hybrid System. Series hybrid characteristics are used at engine start and low speed acceleration and parallel hybrid characteristics are used during high speed acceleration and braking. This system has the highest overall efficiency. However, there are extra components, complexity, and costs associated with it. Current research and development efforts are focused on component downsizing (e.g., the power convertor without compromising energy density) power loss/heat management (e.g., more heat resistant modules and simplified cooling) and finally cost reduction through component standardization (Mastumoto 2005).

2.2.4 Internal Permanent Magnet Motors

Internal Permanent Magnet (IPM) motors, and especially double intelligent power module (IPM) motors, are currently the state-of-art traction motors in HEV applications. Numerous requirements are crucial for their successful operation. Some of these include: high torque and power density, high starting torque, high power at cruising speed, short term overload capacity, low acoustic noise, low torque ripples, maximum variation of d-q axis inductance, least magnet flux leakage, temperature and surface corrosion constraints, excessive open circuit back-emf, and load and no-load stator iron loss at high speeds (Rahman 2008). Apart from control modules and inverters, the V style IPM design utilized by Toyota has been proven superior to both the induction and reluctance motors in terms of electric torque characteristics (Rahman 2008).

2.3 Battery Technologies for Hybrid Vehicles

The earliest automobiles were operated mechanically without the use of electronics. Engines were manually started by cranking the engine with a handle attached to the crankshaft, which in turn rotated the spark plug cap and rotor to initiate engine operation. Since then, automotive technologies have advanced significantly and become more sophisticated, particularly with the addition of electronics. These advancements led to automobiles that produce more power, use less fuel, and are user friendly. Automotive batteries became a necessity on vehicles to start the engine and to power onboard electronics when the engine is not running.

The efficiency of hybrid electric vehicles depends heavily on the capacity of the batteries equipped. Batteries used in electric vehicles are also referred to as “traction batteries”. This efficiency impacts directly the fuel economy of the HEV. As such, battery technology has been an essential research and development topic since the conception of both electric and hybrid electric vehicles. Current battery systems under development are: Nickel Metal Hydrate (NiMH), Lithium ion (Li ion), Lithium Metal Polymer (Li MP), Zebra (Sodium Metal Chloride), and Nickel Zinc (NiZn). Each system has advantages to its design (Wehrey 2004).

2.3.1 NiMH: Nickel Metal Hydrate

Currently, NiMH is the most widely used system in both HV and HEV productions; it is the benchmark for automotive battery systems. It has been successfully implemented with hundreds of thousands of miles logged on both test and production vehicles. Its reliability and relatively low cost are the reason for its tremendous success. However, the weight of this battery type is heavier compared to other designs, which adds to the overall weight of the vehicle (Wehrey 2004).

2.3.2 Li-ion: Lithium Ion

Li-ion batteries will be utilized for the first time on a mass produced automobile in the 2011 Chevy Volt and the 2012 Honda Civic Hybrid (Honda World Wide 2011). The design has superior characteristics in terms of power, energy density, size, weight and performance. With maturing technology, the original high cost is decreasing. Furthermore, the ability to make traction batteries from smaller cells further encourages automotive applications.

2.3.3 Other Battery Types

There are other emerging battery technologies. The Lithium Metal Polymer (Li MP) battery design is not aimed at the HEV industry, but rather EV, telecommunication, or stationery equipment. However, successful EV prototypes have been made such as the Think City EV.

The Zebra (sodium metal chloride) is a high temperature battery targeted for EV applications and can withstand freezing without adverse effects on its cycle. It also has four times the specific energy of conventional lead-acid batteries at 120 Wh/kg. Furthermore, it has no shelf-life issues common to all other battery designs (Wehrey 2004).

Nickel Zinc (NiZn) batteries are aimed at secondary battery applications. This design has not been received well due to its tendency to form dendrites at the zinc electrode. Further developments are needed before this technology can find wide applications.

2.4 Battery Related Performance

Many of the concerns with hybrid vehicles relate to battery performance. Liaw and Dubarry (2007) studied the driving cycle and battery performance of hybrid vehicles in real-life scenarios. The authors suggest that battery performance tests conducted in the laboratory do not always represent what happens during real-life operations. Energy consumption depends on ambient operating conditions and these conditions are difficult to control and therefore measure. The driving cycle term used from this group of authors refers to the speed versus time relationship, while the duty cycle term refers to the power versus time relationship. The road conditions and driving behavior were accounted for and described by the driving pattern term. The challenge is to then correlate the theoretical battery performance with HEV usage in real-life situations.

Liaw and Dubarry (2007) used fuzzy logic pattern recognition (FL-PR) for their analysis of data collected by 15 Hyundai Santa Fe battery-powered electric sport utility vehicles. During the urban driving cycle (stop and go), the traffic and road conditions had an increasing impact on the effectiveness of energy use. The effective force (EF = kWh/km) measured the vehicle performance increased under these conditions. However, it was constant under rural and highway driving scenarios. The authors report that the driving event does not have to match the road type. For example, the stop and go scenario is relevant for urban roads but a driver might encounter the same pattern on a busy highway during rush hour.

The intensity of the peak power and frequency of occurrence are two important factors that affect battery performance and life. Average power and energy consumption can also be used to access the performance and life of batteries. Driving distance and energy consumption showed a linear relationship. An increase in energy consumption with driving scenarios (urban, highway etc.) was not monotonic. In terms of peak power, there is a monotonic increase with the driving scenario. As a result, there is an increase of the peak power with driving scenarios going from local to highway settings (Liaw and Dubarry 2007).

The batteries or any other electrical energy storage unit are sized to achieve appropriate energy (kWh) and peak power (kW) so that the vehicle meets the required performance (Burke 2007). The battery cycle life for deep discharge is an important factor since the batteries are regularly deep discharged. This is true for the electric vehicles and the battery is sized based on the range of vehicle travel. However, for hybrid-electric vehicles, the batteries are sized based on the peak power from the unit during acceleration. The battery stores an amount of energy that is larger than what is needed, but this additional energy allows the battery "to operate over a relatively narrow state of charge range (often 5–10 % at most)". As a result, batteries used in HEVs have longer life and longer cycle life (Burke 2007).

Power density, which is the maximum power the battery can supply, differs from energy density, which is how long the battery can supply the power. There is a tradeoff between these two parameters. In vehicle designs where the battery is used for driving and the engine is used only for high power demands or traveling at speeds above the normal specifications, the fuel economy will be improved. In addition the energy and power requirement will be lower and as a result batteries can be less expensive and smaller in size. Burke (2007) reports that nickel metal hydride (NMH) batteries are the most common types used in hybrid vehicles.

Batteries designed for HEVs are smaller in cell size, have higher power capability and smaller weight because the transfer of energy in and out of the battery should be very efficient. However, the high power density is achieved by trading off the energy density values which in HEV batteries are lower than other vehicles (i.e. EVs). Burke (2007) compared the ability of batteries to withstand charge/discharge cycles between conventional batteries and HEV batteries. In these vehicles the battery was only used to make the engine more efficient and recover energy during braking. There was a 50 % fuel economy improvement compared to conventional gasoline engines. The main engine can be down-sized in "full" hybrid vehicles where the electric motor is larger (50 kW or larger). Nickel metal hydride or lithium-ion batteries can be used and are sized by the power demand. In these vehicles the battery is shallow discharged at an intermediate state of charge (Burke 2007).

3 Hybrid Vehicles: The Environment and Society

The need to reduce the dependency on petroleum based fuels and air pollution concerns has been the driving force toward clean vehicle technologies. In California it has been reported that 51 % of NO_x emissions is attributed to "on-road mobile sources" (Calef and Goble 2007). Several studies have reviewed the potential negative health effects of air vehicle exhaust from emissions such as SO_2, NO_x, and O_3. A number of alternative technologies have the potential to address environmental, economical and social issues associated with ICEVs (internal combustion engine vehicles) such as hybrid-electric vehicles (HEVs), fuel cell vehicles (FCVs) and battery electric vehicles (BEVs) (Turton and Moura 2008). Another potential benefit of HEVs is the control of the place and time that emissions occur: although they are not designed to operate completely using an electric motor, they can be driven as zero emission vehicles if the right battery type is chosen (Calef and Goble 2007).

3.1 Fuel Consumption and Emission Issues

In the late 1990s there was substantial evidence that hybrid vehicles provided improvements in fuel efficiency and reduced carbon dioxide and nitrogen oxide emissions (O'Dell 2000; Easterbrook 2000). Duoba et al. (2005) reported that hybrids were the most fuel efficient vehicles on the market at the time. As an example, the fuel economy of Honda Civic hybrid was rated as 42 mpg (city and highway cycle) while the conventional Honda Civic was 25 mpg (EPA 2008).

D'Agosto and Ribeiro (2004) report that hybrid buses would decrease fuel consumption by more than 20 % and as a result, reduce fuel costs and air emissions. They examined the cost of converting the existing bus fleet with hybrid versions and reported that fuel savings offset the initial increased investment. It was reported that fuel savings between 35 and 40 % were more likely to occur at speeds between 10 and 15 km/h (D'Agosto and Ribeiro 2004). These speeds are very frequently the common travel speeds during traffic jams in metropolitan cities. Furthermore, the highest cost related to conversion of conventional buses to hybrid ones is the battery cost.

Gasoline, hybrid-electric and hydrogen-fueled vehicles were compared in terms of greenhouse gas emissions by Uhrig (2006). CO_2 was used as the main greenhouse gas as the author suggests that it has higher impact and longer residence time compared to other pollutants (i.e. CH_4, NO, CO etc.). It was found that CO_2 emissions for gasoline ICE vehicle are directly related to fuel use. The results show that there was an increase in fuel mileage and decrease in CO_2 emissions respectively. However, these HEVs still depend on fossil fuels and so there is need to develop new technologies in order to reduce dependency on fossil fuels (Uhrig 2006).

Mizsey and Newson (2001) compared several power trains for well-to-wheel efficiencies, CO_2 emissions, and the investment costs. The gasoline internal combustion engine (ICE) was used as a baseline for comparison and the other alternatives considered were hybrid diesel, fuel cell operating with hydrogen produced on a petrochemical basis, methanol reformer-fuel cell system, and gasoline reformer-fuel cell system. The gasoline ICE had the highest CO_2 emissions, but the cost for the gasoline engine powertrain is the lowest. If the vehicles are therefore compared only on environmental basis the ICE gasoline powertrain has the worst performance. In terms of the well-to-wheel efficiency the hybrid diesel comes out first: it has the lowest CO_2 emissions along with the compressed hydrogen produced by natural gas technology (Mizsey and Newson 2001). These findings are encouraging for developing hybrid diesel vehicles and their commercialization, which to date, has not enjoyed the same visibility as hybrid gasoline-electric vehicles.

Vehicle exhaust contains a number of greenhouse gases and contaminants identified as contributors to air pollution. Significant advancements have been made through after-treatment technologies in order to reduce the effect of vehicle exhaust to the environment. Alternative technologies and fuels have been investigated and implemented in order to achieve emission reduction while maintaining vehicle performance. It has been reported that through improvements in technology, it has been possible to reduce emissions up to 95 %. Karman (2006) emphasizes that these alternative technologies and fuels should be carefully evaluated through life-cycle analysis (LCA) in order to claim their real benefits.

3.2 Using Life Cycle Assessment to Evaluate Hybrid Technologies

Life cycle assessment or analysis (LCA) has emerged as key tool for comparing the performance of different products or processes, both before/after changes and as compared to other products/processes, because of its ability to assess a much broader context. The LCA framework is illustrated in Fig. 1. As an example of the benefits of using LCA for evaluating hybrid vehicle technologies, Karman (2006) used GHGenius, GREET, and CSIRO LCA models to compare greenhouse gas emissions between diesel and compressed natural gas (CNG) buses in Beijing. Even though natural gas yielded lower CO_2 emissions during the operation stage and also from upstream operations compared to diesel, natural gas buses produced more CH_4. CH_4 has a 21:1 greenhouse gas potential ratio (CH_4:CO_2) when compared to CO_2. A complete LCA thus revealed that the total CO_2-equivalent life-cycle effect was higher for CNG than for diesel (Karman 2006).

The benefits of LCA for evaluating environmental impacts of transportation systems have also been discussed by Stanciulescu and Fleming (2006). The authors also give a detailed description of the GHGenius model which was

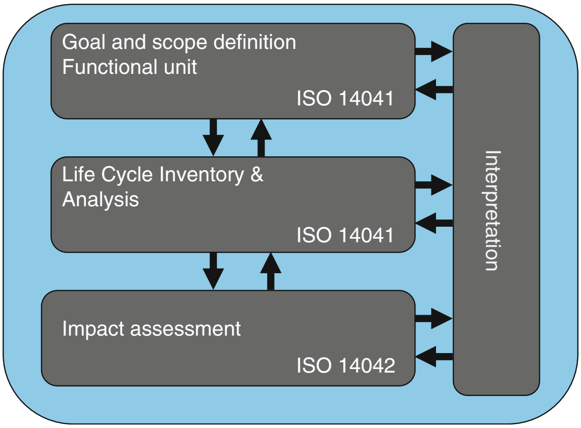

Fig. 1 LCA framework (adapted from ISO 14040 2006)

developed for Natural Resources Canada and contains detailed information related to fuel cycles and can be used to model and predict the environmental impact of conventional and alternative fuels and propulsion systems. The model has been successfully used by the government and industries in many studies, and is best fitted for Canadian scenarios. The GHGenius is capable of analyzing emissions from different vehicle and fuel combinations, which makes it an attractive model for researchers.

3.3 Diesel Benefits and Impacts

Diesel vehicles have not yet attracted widespread consumer attention in North America (Albert et al. 2004). Some of the reasons are related to the soot and noise generation and NO_x emissions. However, advancements in technology have targeted some of these issues and as a result there have been many improvements. It has been reported that diesel engines are more efficient than gasoline engines and the use of turbo charging can increase the performance of diesel engines so that they are comparable to gasoline engines.

The fuel pathways for gasoline, diesel, biodiesel and ethanol blended diesel are particularly critical. Interestingly, Stanciulescu and Fleming (2006) showed that the energy use for well-to-tank case was the same for both diesel and biodiesel fuel production stage. The same trend was also observed about the GHG emissions from these two fuels during the well-to-tank stage. However, both diesel fuels show lower energy use and GHG emissions than reformulated gasoline with 30 ppm sulfur content. Most of GHG emissions are released during the vehicle operation stage from reformed gasoline ICE and hybrid vehicles: the same can be said for diesel and diesel hybrid types. However, in both gasoline and diesel cases the hybrid alternative has lower GHG emissions during the operation stage. Overall out of these four scenarios it is the diesel hybrid that yields the lower GHG emissions in g/km CO_2 equivalents (Stanciulescu and Fleming 2006).

The majority of hybrid electric vehicles (HEVs) produced to date have a gasoline engine. In the last few years however diesel hybrids have been the focus of research (Albert et al. 2004). One benefit of these hybrid vehicles is the high flashpoint of diesel which adds to the safety of the vehicle in a collision scenario. The authors used ADVISOR to simulate the fuel efficiency of large and small diesel hybrid vehicles. It was reported that for the large hybrid SUV there was a 25 % improvement in fuel economy for a hybrid factor of 0.1. The hybrid factor (HF) is the ratio of the power of electric motor over the power of both electric motor and main engine combined. The economy increased with the increase in HF, but the performance suffered. The optimum fuel economy (21.6 mi/gal) was achieved at $HF = 0.6$ and indicated a 44 % improvement compared to the conventional SUV. However, the maximum speed that could be achieved was 82 mph. For the small SUV an HF of 0.6 was still the optimum with a fuel economy of 26.1 mi/gal and a 97 % increase from conventional vehicle; however the maximum speed was 81.6 mph (Albert et al. 2004).

The output power of the battery was compared with the output power of the electric propulsion motor. It was found that fuel economy was not improved when the output power of the battery units was matched to the power of the electric motor. Conversely, the fuel economy decreased due to the weight increase caused by addition of battery units. The maximum speed did not increase significantly, but this is in contrast to the fuel economy which decreased. The performance factor that was improved significantly was the gradeability, or the ability of the vehicle to ascend a slope, because of the addition of the batteries. The authors suggest that for hybrid diesel engine vehicles, the tradeoff between increased graedability, maximum speed and acceleration against the fuel economy make hybrid diesel engine vehicles as an attractive choice (Albert et al. 2004).

Turton and Moura (2008) also examined the potential of using HEVs as energy sources. There are vehicle-to-electricity grid technologies that could harness the energy stored in the HEV while not in operation and then feed it into the electrical grid. For HEVs the amount of electricity delivered by the battery equals the amount of electricity needed to recharge it and as a result, using HEVs as energy sources is feasible.

3.4 Socio-Economical Issues

In addition to improvements in air quality and fuel consumption there are social benefits associated with HEVs. For example they are seen as the “first realistic technological option for private transport that does not rely exclusively on gasoline” (Calef and Goble 2007). Other researchers discuss the changes in driving habits and attitudes that the use of HEVs and electric vehicles could bring. Brown (2001) reports that consumers driving hybrid electrical vehicles were more likely to plan their trips carefully reduce driving time and in general become more aware of the social implications of the transportation system. HEVs do not provide the functionality that would enable or permit inefficient or undesirable driving habits, such as “jump starts”. Given that such behaviors are not desirable for any vehicle type, purchasing an HEV could be an opportunity to change driving habits toward safer and more responsible patterns and behaviors (Row 2009).

There are additional issues to consider in relation to HEVs. For example, the initial purchase cost of an HEV is higher than conventional vehicles, but the operating cost is much lower due to fuel consumption reduction. Salmasi (2007) also acknowledges that HEVs are the most economically viable solution, but also argues that savings of 70 % per gallon can be easily undermined by the amount spent on changing batteries, ultra capacitors, and so on, and as a result there is need to design a system that considers different energy portfolios. In addition, special consideration should be given to the design and development of drivetrain, control structures (which can be complex in HEVs), and vibration control in the vehicle (Salamasi 2007).

Maggeto and Mierlo (2001) state that the usage of the vehicle should be considered when “planning a suitable hybrid vehicle”. The automotive purchase price is usually the baseline criteria for selecting a vehicle, but the reduced fuel consumption, emissions and changes in energy price should be taken into consideration: the “sticker price” therefore does not necessarily represent the real cost (Maggetto and Mierlo 2001).

It is also critical to consider economic issues associated with alternative transportation technologies. Granovskii et al. (2006) considered vehicle price, fuel cost and driving range as key economical variables in comparing different vehicle/fuel technologies. The vehicle price also included the additional cost for changing the batteries in hybrid and electrical vehicles. In terms of environmental factors, GHGs and air pollutants (APs) were included in the equation. Based on the analysis of the four vehicles compared (conventional gasoline ICE, HEV, EV and hydrogen FCV), the electricity generation scenario for fuel production impacts significantly the outcomes. If 50 % of the energy used to produce electricity comes from nuclear and renewable resources, then hybrid and electric cars become competitive. If however, fossil fuels account for more than 50 % of the energy sources, than hybrid cars are more advantageous than their electric, conventional and fuel cell counterparts (Granovskii et al. 2006).

The societal lifecycle cost (LCC) of several fuel/engine combinations was also investigated by Ogden et al. (2004). The authors consider the cost of vehicle and fuel, the cost for oil supply security and environmental costs due to GHG and air pollutant emissions. The vehicle/fuel options considered were compared against an advanced gasoline ICE vehicle that met Tier II air pollution standards. The options included:

- ICE vehicles fueled with hydrogen;
- ICE hybrid electric with gasoline, compressed natural gas, diesel, Fischer–Tropsch liquids, or hydrogen; and
- Fuel cell vehicles fueled with gasoline, methanol or hydrogen.

When costs for oil supply insecurity and environment (GHG and AP) are included in the overall lifecycle cost, all advanced options with the exception of FCV are less expensive than current gasoline SI ICE vehicle that is common today. The authors further report a damage cost from GHG emissions as \$14–\$510 per tonne of carbon as CO_2-equivalent. However, when the externality costs are not included, today's car has the lowest price. This reinforces the fact that environmental and fuel dependency factors when included would yield a reduced lifecycle vehicle cost. However, the problem is the value that society puts on such externalities.

3.5 Barriers to Hybrid Technology Adoption

Maclean and Lave (2003) used LCA to assess various vehicle and fuel options. They discovered that consumer acceptance can be a barrier to developing more environmentally friendly vehicles. For example, large vehicles have been supported by a large number of consumers and have slowed down the process of developing "greener" vehicles. Another issue is the contradictory nature of regulatory and societal goals. A smaller vehicle would satisfy sustainability principles developed by Anastas and Zimmerman (2003), however it could compromise safety and other regulations. Maclean and Lave (2003) suggest that the vehicle design and development stage is the most important one in creating sustainable vehicles. The vehicle operation (usage) stage contributes the most to GHGs in terms of CO_2 equivalents. Light duty vehicles that use diesel as fuel have an efficiency of 24 % compared to the gasoline ICE vehicles that have an efficiency of 20 %. As a result, diesel engine vehicles have the potential of higher fuel economy. Diesel has high carbon content, but because its production and vehicle efficiency are higher than for gasoline, it can reduce GHG emissions. The problem is that these vehicles have high NOx and PM emissions and are not highly sought by North American customers. HEVs achieve higher fuel economy and lower emissions, but on the other hand are more expensive and complicated in design. HEVs could become competitive with the conventional ICE through implementation of technological advancements that could increase fuel economy, lower emissions and vehicle initial price as well as increased social values assigned to GHGs or APs. Assigning a dollar value to environmental and social aspects is not always the preferred choice, however it does allow for comparisons between vehicle and fuel technologies. If all societal, economic, environmental factors as well as regulatory and customer goals are considered there is not one vehicle/fuel technology that is superior in all aspects (Maclean and Lave 2003).

Another issue to consider is the need for new infrastructure to deliver energy to vehicles using alternative powertrains. The authors report that if externality costs are valued low, then the advanced technologies cannot compare with the reference car unless the drivetrain does not cost more than the reference. In contrast, if the externalities are valued high then the advanced options would be competitive even if the cost of drivetrain is more than the reference car. In general, fuel-efficient liquid hydrocarbon fueled ICEVs and ICE-HEVs can achieve significant reduction in environmental and fuel uncertainty costs and also require minimum infrastructure changes. Even though the hydrogen fueled car yields the lowest cost when the externalities are valued high, the cost of implementing the infrastructure to deliver the hydrogen to consumers does not make it an attractive option in the near future (Odgen 2004).

4 Idle Reduction or Assistive Technologies for Fleet Vehicles

The availability of inexpensive petroleum based fuel has led the internal combustion engine (ICE) to dominate as the main propulsion system in motor vehicles. The convenience of petroleum fuel comes with a penalty principally in the form of tail pipe emissions. The operation of motor vehicles has become essential for transporting people and goods, but the drivetrain also powers onboard electronics and maintains the vehicle occupants comfortable. While engineers and designers optimize the ICE's efficiency to reduce fuel consumption and emission during operation, there is a trade-off in the ICE's idling efficiency. The ICE generates excessive power for idle conditions, wasting fuel and creating unnecessary emissions.

In 2007, the U.S. Department of Commerce's Vehicle and Inventory Survey estimated there are more than 400,000 commercial/transport trucks in service in the U.S. and each travels more than 500 miles a day (Lutsey et al. 2007). As illustrated in Table 2, the EPA estimates 960 million gallons of fuel are wasted per year from idling commercial trucks alone and the associated emissions include 180,000 tons of nitrogen oxide (NO_x), 5,000 tons of particular matter (PM), and 11 million tons of CO_2 (Frey and Kuo 2009). In response, a number of technologies for idling reduction (IR) have been pursued over the last two decades. Currently, the commercially available technologies are mainly for heavy transport truck. Passenger vehicles, however, have started to incorporate similar IR technologies. More generically, we can refer to these technologies as *assistive technologies* as they assist in the functioning of the vehicle services, and may in the future provide more functionality than simply reducing the impacts from idling.

IR technologies can be divided into two categories: onboard and wayside. Onboard technologies are installed on the vehicle itself to operate during idling. Wayside technologies are external infrastructure built to provide the necessary

Table 2 Long haul truck idling facts (U.S.) (adapted from Frey and Kuo 2009)

Vehicle and fuel statistics	
Number of trucks on the road	>400,000
Amount of diesel fuel used	960,000,000 (gallons)
Associated emissions	
NOx	180,000 (tons)
PM	5,000 (tons)
CO_2	11,000,000 (tons)

idling needs of the vehicles. Trucks have both onboard and wayside IR technologies available to them. They can be retrofitted or OEM equipped (Gains and Levinson 2009). Some technologies are mechanical modifications that reduce the fuel consumption of the ICE, while others function only during idling (Lim 2002).

4.1 Onboard Technologies

There are several onboard technologies that are used for idling reduction purposes. The most common types are:

4.1.1 Engine Start-Stop Control

This technology operates when a vehicle slows down to a complete stop. The onboard electronic control unit (ECU) then turns off the engine to prevent idling. The engine is restarted as soon as the brake pedal is release (automatic transmission) or when first gear is selected (manual transmission). An integrated starter-generator (ISG) is used instead of the conventional starter and alternator to provide the necessary engine cranking power without draining the battery.

4.1.2 Cylinder Deactivation

Under ideal conditions, fuel injection is ceased temporarily in designated cylinders of the engine to eliminate combustion. The 4-stroke cycle continues without combustion. Some systems open the exhaust valve(s) during the compression stroke and the intake valve(s) during the power stroke to minimize pumping loss. Cylinder deactivation is typically used on large displacement engines with six or more cylinders to operate temporarily the engine with only four cylinders firing to reduce fuel consumption. Uneven wear between the cylinders can occur however, and ECU controls can alternate the deactivated cylinders to prevent this.

4.1.3 Auxiliary Power Unit

An Auxiliary Power Unit (APU) is an external diesel powered generator installed into trucks. During extended idling, the main ICE is turn off and the APU is used to power the heating ventilation and air condition (HVAC) systems and all other accessories. Frey and Kuo (2009) reported that APU can reduce the fuel consumption by 36–47 %. Similar reductions were reported for SO_2 as well. In terms of other air pollutants it was found that NO_x emissions were reduced by 80–90 % while PM, CO, and HC emission reductions ranged from 10 to 50 %. However, APUs add extra weight, and cannot be used in ‘creeping’ conditions such as when slowly queuing at a border crossing (Frey and Kuo 2009).

4.1.4 Cab and Block Heater

During extended idling, waste heat recirculation from a small diesel heater is used instead of the ICE to heat the cabin and to maintain engine fluid temperature preventing cold weather engine start difficulties. Because no cooling can be provided, this configuration only works in cold weather conditions.

4.1.5 Air Conditioner

A battery powered air conditioning (A/C) system can be installed for use during extended idling when main ICE is turned off to save fuel. A secondary battery pack is charged during vehicle operation. Evaporative cooling and thermal storage are also available, but these additional functions can make the cost prohibitive. Because no heating can be provided, this configuration only works in hot weather.

4.2 Wayside Technologies

Wayside technologies are less common when compared to the onboard technologies. The most common types are: (1) single system; (2) dual system/shore power; and (3) fluid circulation systems.

4.2.1 Single System

Electrified parking spaces are built at rest stops or designated areas to provide HVAC for trucks when an extended stay is required. The charges depend on the user. Rest stop owners that install such wayside equipment can earn revenues by charging electricity usage (Gaines and Levinson 2009). However, the long term viability is still to be determined as this system is fairly new.

4.2.2 Dual System/Shore Power (SP)

This technology is similar to single system, but the electrified HVAC system is installed on the truck, which incurs an initial capital investment on drivers. The parking spaces need to have an electrical outlet built in, which translates on an increased capital investment for facility owners. Idling is eliminated and electricity cost is lower compared to diesel fuel (Gaines and Levinson 2009).

4.2.3 Fluid Circulation System

This technology is mainly used on buses at certain parking areas such school yards. The vehicle's coolant system is connected to an externally heating system and re-circulates the heated fluid to warm the bus during extended stays. However, this option requires significant capital investment and does not provide cooling and therefore is only effective in cool weather.

4.3 Applications to Fleet and Passenger Vehicles

Incorporating idling reduction systems or emerging assistive technologies on passenger vehicles is a recent development, most likely because of the increasing pressures to achieve sustainable modes of transportation. There are onboard IR technologies for non-commercial passenger vehicles (Stodolsky et al. 2001). However, the individual mobility of passenger vehicles works against wayside systems. Onboard technologies consist mostly of engine start-stop controls and cylinder deactivation battery systems. Other options being explored include battery systems. These may in fact become necessary as more traditional mechanical automotive systems (e.g., throttle control, power steering) become electrified.

Extended fuel consumption and air emissions are attributed to the unique operations of fleet vehicles and in particular, during idling. While drivers of passenger vehicles may have the option of simply not idling, fleet operators—and in particular emergency vehicle operators—may need to keep the vehicle operating to provide power to operate critical onboard equipment (e.g., computers, life saving equipment). These demands may be exacerbated during temperature extremes. However, prolonged idling can impose significant environmental and economic burdens. Hybrid vehicles have yet to be utilized widely by fleets, but there are other approaches to reduce emissions, including idling reduction technologies to operate in-vehicle equipment and maintain fleet vehicle capabilities instead of idling.

Overall, there are few studies published in terms of environmental and socio-economical impacts associated with the use of idling reduction technologies. However, IR or assistive technologies also share some of the advantages and disadvantages—albeit on a reduced scale—associated with hybrid electric vehicles because a number of them use conventional or extended batteries to reduce idling.

4.4 Driver Behavior

One important aspect to consider for the success of IR technologies is the driver "behavior" toward such technologies and how the driver interacts with the vehicle during routine or specialized activities. For example, if an IR technology is installed in a police vehicle, it should provide the necessary power to maintain laptop connectivity, emergency lights, and so on. Another example is maintaining the cabin temperature. The IR technology can be pre-programmed to keep the engine off until the cabin temperature drops/raises to a certain temperature depending on season. However, not all fleet operators have the same sensitivity toward temperatures. As a result, small but important considerations may influence significantly the drivers' attitudes towards adopting IR technologies.

4.5 Battery Recycling

Many types of batteries are available for automotive use; however, the lead acid battery (LAB) is currently the industry standard for automotive starting, lighting and ignition (SLI) as well as idling reduction (IR) technologies. Even with their low specific energy, LABs can withstand the automotive charge/discharge cycle better than other batteries and provide a high surge current. Its ease of construction also makes it ideal for mass production at low cost. However, should IR technologies be increasingly applied to fleet operations, there is significantly greater volume of batteries and different batteries that must be installed and eventually handled at their end-of-life, particularly when fleet vehicles turnover en masse.

LAB end-of-life (EoL) strategies have long been established and consist primarily of disposal (landfill) or recycling. Both strategies have their associated advantages and disadvantages in terms of the environmental impacts. According to Genaidy et al. (2008), LABs account for 88 % of the lead consumed in the U.S. with a 2.25 % increase in consumption each year. The disposal and recycling practices are therefore crucial in ensuring a sustainable life cycle of LABs. In addition to being sustainable, EoL strategies for LABs need to be economically feasible as well. Fisher et al. (2006) divided the financial costs of LAB EoL strategies into the following categories:

- Collection—this includes both labor and transportation costs. Collection cost is inversely proportional to volume. As volume increases, collection cost decreases.
- Sorting—a labor intensive step at local/regional waste facilities to separate the various types of batteries.
- Operation—operating procedures depend on the individual strategy and jurisdiction.

Collection and sorting cost can be assumed to be approximately the same for both disposal and recycling strategies. However, the operational costs are very different. The advantages and disadvantages of each EoL strategy can be evaluated by considering their economic feasibility and environmental impacts.

Strategy 1: *Disposal*

State-of-the-art landfill processes and controls better contain both air and water lead emissions. Processes and controls such as barrier layers in sanitary landfills can minimize heavy metal emissions to the environment (Fisher et al. 2006). With the increasing public opposition towards landfills and the growing scarcity of land due to population growth, the cost of landfills has been increasing steadily making this strategy less appealing. As a result, incineration has been growing in popularity, especially in high population density areas such as the European Union (EU). Incineration has an added benefit of energy recovery (combustion to electricity) that can be transferred back into the grid. However, the air emissions generated from the incineration processes have a negative impact on the environment and to a certain degree offset the benefits of this strategy. Both landfill and incineration have lower financial costs and have simpler logistics as compared to recycling.

Strategy 2: *Recycling*

LABs recycling is inherently energy intensive. Nevertheless, recycling and recovery rates of LABs have been high. The useful life of LABs is 4 years and the weight of lead content in each LAB is about 11 kg (Genaidy et al. 2008). It has been estimated that in 2003 about 2.6 million metric tons of lead are in the batteries of vehicles on the road (Environmental Defense 2003). Considering these values and the many vehicles on the road today, it is extremely important to consider recycling strategies that ensure the extraction of lead from LABs. The current practice is to pyrometallurgically extract metallic lead in rotary kilns. The breakdown of LAB components have been reported by Fisher et al. (2006) and are summarized in Table 3.

In the recycling process of LABs, H_2SO_4 (sulfuric acid), plastics and other materials are removed by combustion. However, this creates SO_2 and SO_3 that also contribute to acid rain and global warming gases such as NO_x (Volpe et al. 2009). The advantage of LAB recycling is to create a closed loop in the production life cycle, which in turn reduces the need for virgin lead. More research is necessary to

Table 3 Summary of LAB components (adapted from Fisher et al. 2006)

Component	%
Lead	65
Other metals	4
Sulfuric acid	16
Plastics	10
Other materials	5

increase the efficiency of current processes and to develop innovative technologies. At present, the costs of liquid fuel and electricity along with equipment and labor costs render recycling more costly in comparison to landfill disposal.

4.5.1 Environmental Assessment of LABs

Daniel and Pappis (2008) defined three environmental impact categories in their life cycle assessment of LABs: (1) resource consumption; (2) ecological impact; and (3) working environment impact. Apart from raw material consumption (lead, other metals, water, H_2SO_4, and plastic polymers), fuel and electricity are also consumed in the production of LAB. These impacts can be offset by recycling, which reduces the need for virgin raw materials. The main environmental impacts from all stages of the LABs lifecycle are summarized below.

- ***Global Warming/Greenhouse Effect***
  Measured in global warming potentials (GWP). All carbon emissions are converted to CO_2 equivalent in a 100-year time frame. For example, methane gas (CH_4) has 25 times the GWP as CO_2. For LABs, the stages that contribute the most to GWP are the collection (material) and distribution processes.
- ***Photochemical Ozone Formation***
  Caused by the release of volatile organic compounds (VOC) in the troposphere from the LABs life cycle. Similar to global warming, the production of VOCs is mainly from the collection and distribution processes.
- ***Acidification***
  Created from SO_2 emissions due to lead processing in the rotary furnaces after material collection and pryometallurgical recycling.
- ***Eutrophication***
  Occurs when nitrogen enters water bodies from transporting raw materials and the recovery/recycling processes.
- ***Eco-toxicity***
  Occurs mainly from the release of heavy metals and other hazardous materials into the environment. If LABs are disposed through landfill, then lead and acid are released into the soil. Air emissions would come from the incineration process. If recycling strategy is considered then lead, acid, and formaldehyde are released during pyrometallurgical processes.

The impacts from the production and assembly processes can be offset if large scale and efficient collection and recycling can be implemented (Bossche et al. 2006). However, many researchers regard this offset as a displacement of impacts, not as a true reduction of potential impacts. Nevertheless, without recycling and recovery, LAB life cycle will never become closed loop and eventual depletion of resources will occur.

The conventional disposal (landfill) of LABs promotes an open loop life cycle. Even with the added cost, recycling (recovery) of lead is essential to create a closed loop life cycle that will be sustainable. Since the initial 2004 EU Directive on batteries and accumulators, the battery industry has established the *Green Lead Vision* to make the industry as a whole more sustainable. Technological advancements in LABs recycling will continue to lower cost and environmental impacts. The move to hydrometallurgical LAB recycling by using cementation (reduction reactions) or electro-hydrometallurgical processes can lead to recovery rates as high as 99.7 % (Volpe et al. 2009).

5 Conclusion and Recommendations

Over the last four decades, there have been rapid developments in the hybrid vehicle technology, and in particular gasoline-electric powertrains. In addition ultra-clean diesel fuels have gained increasing interest. HEVs and clean fuels are seen as alternatives to conventional vehicles to conserve the natural resources and also protect the environment. There are several benefits attributed to the use of HEVs/clean fuel systems and particularly urban travel scenarios:

- Greater fuel efficiency than conventional gasoline cars;
- Substantial emission reduction;
- Reduced operating cost due to lower fuel consumption;
- Potential for the vehicle-to-grid technology to harness stored energy;
- Potential to enable changes in driving habits and attitudes; and
- Reduced health costs due to the improvement of air quality.

While these benefits cannot be realized in every operating scenario, HEVs can provide tangible economic and pollution control benefits in specific scenarios and furthermore, can provide potential significant and broadly-based environmental, health, and socio-economic benefits.

Fleet operations can benefit from hybrid technologies as well, but also from idling reduction technologies and assistive technologies. IR technologies have tremendous potential to reduce the impacts from idling. The immediate end users that will directly benefit from the outcomes of implementation of such technologies are fleet operators. The potential applications can be used by fleet operators as well as designers, engineers, non-governmental organizations, policy makers, and regulators to produce and commercialize vehicle technologies that will reduce environmental impacts from fleet operations. In particular, they may aid in establishing the rationale for IR technology suppliers and vendors as they promote the business case for their technologies. Finally, it may permit policy and decision makers to make more accurate decisions about the operation of fleet vehicles to reduce their environmental impacts while enhancing socio-economic benefits.

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