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Energy recovery systems for retrofitting in internal combustion engine vehicles: A review of techniques

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ABSTRACT

Energy recovery systems (ERSs) for internal combustion engine vehicles (ICEVs) are reviewed in the context of fuel efficiency improvement and retrofit capabilities. The paper presents technical knowledge on the potential benefits that retrofitted ERSs may achieve in carbon emissions reduction. A first distinction of ERSs is made between the sources of the energy and further sub-divided on the technique to harvest and store the energy. A critical evaluation is performed on the associated characteristics such as weight, size and cost. Finally, the paper summarizes the ERSs technologies under a number of common criteria, and finds out, that the most effective ERSs in terms of fuel efficiency are the ones more difficult to retrofit. Further research is suggested to investigate the trade-off between fuel consumption reduction and investment cost of the system.

Contents

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1. Introduction

Energy recovery systems (ERSs) for automotive applications are defined as the techniques to recover the energy of the vehicle that otherwise would have been wasted. The recovered energy can be stored and then used when necessary, reducing the need for further energy source or fuel, and therefore improving the overall efficiency of the vehicle. ERSs may be applied in a vast range of technologies within powertrains for automotive industry. It is only ERSs that potentially offer short and medium term solutions to the problem of vehicle population growth and the associated emissions. Within the European Union (EU), emissions from road transport are estimated 23% of the total CO_2 levels. To reduce car pollution, the EU has set targets for average CO_2 tailpipe emissions at 130 and 95 gCO_2/km for 2015 and 2020, respectively. However, with the 2009 average actual tailpipe CO_2 emissions at 145.7 gCO_2/km, there are challenges in retrofitting, cost and impact on the whole vehicle system and within the transport system [1,2].

1.1. The market

The field of energy recovery (ER) has been the subject of research and innovation in patents since the 1970s [3–5]. However, the automotive industry has normally focused in more traditional fields to enhance the fuel efficiency of vehicles, such as engine efficiency or aerodynamics. It is only in recent years that manufacturers have realized that ERSs present a cost-effective alternative to improve efficiency, and therefore the potential benefits of those systems are being fully developed.

In fact, ERSs are currently found in some vehicle models, regardless of the type of powertrain. Manufacturers such as BMW and Renault already integrated ERSs in internal combustion engine vehicles (ICEVs) [6,7]. On the other hand, hybrid electric vehicles (HEVs) such as Toyota Prius and battery electric vehicles (BEVs) such as Nissan Leaf already feature kinetic energy recovery systems (KERSs) within their powertrain also known as regenerative braking technique [8,9]. In an automotive industry clearly focused on efficiency gains, the increasing number of new vehicles performing ERSs highlights the benefits obtained by this technique in terms of energy usage.

In the United Kingdom the financial incentives for alternative vehicles have doubled the sales for HEVs from 2007 to 2012. However, the market share has only been rising slowly from 0.7% to 1.3% [10], while BEVs have shown even more marginal results [11]. In spite of the increased sales of EVs and associated financial support schemes as well as the technology promise of fuel cell vehicles (FCVs), their world market penetration will not be significant in the short and medium terms. This is illustrated in Fig. 1, showing the sales forecast for passenger light duty vehicles (LDVs) under the International Energy Agency (IEA) BLUE Map scenario and based on a 50% fuel efficiency improvement by 2050 over 2005 levels. EVs and FCVs would not be majority in the vehicle parc, the population of vehicles on the road, until 2065–70 considering a realistic LDV lifetime of 15–20 years [12].

In addition, major markets such as in the EU and the United States (US), new vehicle sales figures are not expected to increase significantly while second hand vehicle market is on the rise. In the EU the vehicle parc increased but sales fell short since 2007 [13]. This would allow a greater impact in emissions on the current vehicle parc and motivation towards retrofit systems to enhance efficiency in the sector.

1.2. The sensitive HEVs and BEVs role on GHG reductions

Life cycle analyses (LCAs) for vehicle technologies have mostly taken the full approach from cradle to grave. That is, taking into account not only the emissions related to the use of the vehicles but also the associated emissions to manufacturing and disposing. A common approach in these studies for the life cycle impact assessment (LCIA) method is the quantification of the equivalent green house gas (GHG) emissions, which are a measure for global warming potential (GWP). These LCA studies have demonstrated that the potential benefits of HEVs and BEVs over conventional ICEVs depend on a number of variables, and in particular cases they may not demonstrate a clear advantage [14–17].

LCA studies have shown that GHG emissions associated to the manufacturing process are higher in HEVs than in ICEVs. However, this difference may be offset during the usage phase of the vehicle, attributed to the increased fuel efficiency of HEVs. For instance, for a typical HEV at an annual mileage of 10,000 km, it would require 5 years to offset the extra GHG emissions associated with manufacturing over the ICEV, which may be achievable for an average driver [14,15]. However, if an existing ICEV, that has a residual value, is replaced by an HEV, the offset period would increase up to 14 years due to all the manufacturing emissions.

BEVs have shown even higher GHG emissions associated to the manufacturing process than HEVs, which requires a greater offset [14,15]. However, emissions associated to the usage phase of BEVs strongly depend on how the electricity is produced. For instance, a BEV sourced with low-carbon electricity, such as renewable

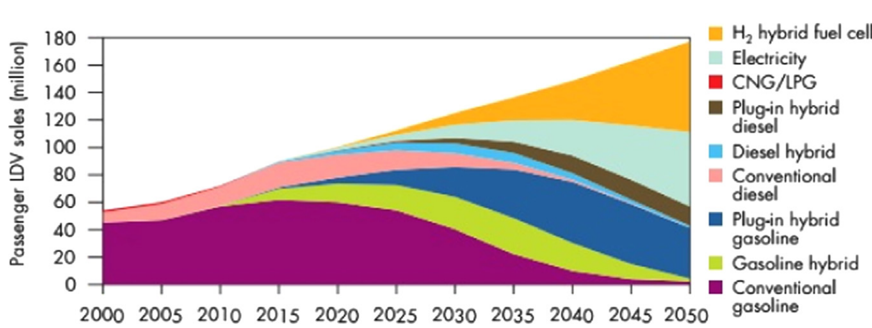

Fig. 1. IEA market forecast [12].