

Life cycle cost analysis of a car, a city bus and an intercity bus powertrain for year 2005 and 2020

Jonas Hellgren*

General Motors Powertrain, Sweden AB, A21-2 FTTCF, 461 80 Trollhättan, Sweden

Available online 17 November 2005

Abstract

The international economy, in the beginning of the 20th century, is characterized by uncertainty about the supply and the price of oil. Together with the fast decrease of electrical propulsion component prices, it becomes more and more cost effective to develop vehicles with alternative powertrains. This paper focuses on two questions: Are alternative powertrains especially cost effective for specific applications?; How does an increased fossil fuel price influence the choice of powertrain? To assess these questions, a computer tool named THEPS, developed in a Ph.D. project, is used. Three applications and three scenarios are analysed. The applications, a car, a city bus and an intercity bus, are vehicles all assumed to operate in Sweden. One scenario represents year 2005, the other two year 2020. The two future scenarios are characterized by different fossil fuel prices. The study, presented in the paper, indicates that alternative powertrains can be competitive from a cost perspective, in some applications, already in year 2005. It is for example cost effective to equip a city bus, running in countries with a high fuel price, with a hybrid powertrain. The study also indicates that pure electric, hybrid and/or fuel cell cars will probably be a more cost effective choice than conventional cars in year 2020. Another indication is that it will not be clear which powertrain concept to choose. The reason is that many cost effective powertrain concepts will be offered. The best choice will depend on the application.

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Keywords: Alternative powertrains; Hybrid vehicles; Life cycle cost

1. Introduction

Increased energy demands, combined with limited fossil fuel sources and the environmental concern, are huge challenges for the humankind. The greatest increase in transportation energy consumption will occur in the developing world.

Vehicles with an internal combustion engine (ICE), as single power source, have for a long time dominated the market. However, more energy efficient alternative powertrains,¹ like hybrid powertrains, become more and more attractive. The major reasons are the reduced cost of electrical components and the risk of higher fossil fuel prices.

Many design options are present when it comes to powertrain design. The powertrain components can be configured, chosen and sized in numerous ways. The most cost effective choice depends on factors like fuel price, application and interest rate. Especially, in future when many powertrain concepts will be offered, it will not be clear for a customer which powertrain to choose.

Several papers deal with the economical impact of different fuels, in transportation, from a societal perspective, some examples are Specht et al. (1998), Azar et al. (2002), Hekker et al. (2003) and Ogden et al. (2004). These studies focus on comparing different fuel chains² or technical aspects in the vehicle. Typically a cost model, that includes the capital cost of the vehicle and the fuel cost, is included. The powertrain models are normally very

*Tel.: +46 707 686890.

E-mail address: Jonas.AK.Hellgren@se.gm.com.

¹The powertrain and its most vital components are described in Section 2.

²An example of a fuel chain is gasoline. First oil is pumped from the ground, then it is refined into gasoline that needs to be transported to pump stations. Finally, the gasoline is combusted in a vehicle. An efficient fuel chain is characterized by low losses in the transformation phases.

Nomenclature		E	Energy (kJ)
a	Acceleration (m/s ²)	η	Efficiency (dimensionless)
c	Cost (Euro/km)	m	Mass (kg)
		v	Speed (m/s)

simple, in Specht et al. (1998) the energy conversion in the powertrain is modelled by a constant efficiency. The characteristics of the different powertrain types are derived from real vehicles or from computer simulation, in Hekker et al. (2003) it is assumed that hybrid powertrains have 50% lower fuel consumption compared to the conventional powertrains. There are also numerous papers that deal with detailed computer simulation of a given powertrain, some examples are Lyshevski (2000), Butler et al. (1999) and Wipke et al. (1999). By detailed computer simulation, virtual tests of powertrains can be performed to study technical aspects in a vehicle. Examples of earlier studies that focus on costs, connected with the use of a vehicle, are Cuenca et al. (2001), Lipman and Delucchi (2003), Cuenca et al. (1999), Burke (2003), Vyas et al. (1999), Mizsey and Newson (2001), Ekdunge and Råberg (1998) and Forsberg (2003). In this paper, a smaller set (2–5) of powertrains, are prescribed. Their performance, fuel consumption and other characteristics are typically determined from computer simulation. Comparisons for different parameter setups are then often made, fuel price can be the parameter varied.

The purpose of this paper is to assess powertrain choices for different applications and scenarios. Two key questions are highlighted:

- (Q1) Are alternative powertrains especially cost effective for specific applications?
- (Q2) How does an increased fossil fuel price influence the choose of powertrain?

The difference from similar studies, previously cited, is that the powertrain design is not prescribed. In this study, a computer tool automatically finds the lowest cost powertrain design, given constraints and prerequisites. The author has not found any work that considers, in a systematic way, that the powertrain design highly depends on constraints and prerequisites.

In Section 2, different powertrain technologies are presented. A computer tool THEPS, developed in a Ph.D. project to optimize powertrains, is described in Section 3. Assumptions and limitations are presented in Section 4. The main contribution of the paper, a life cycle cost analysis of a car, a city bus and an intercity bus, is presented in Sections 5–7. In the end of the paper conclusions are drawn.

2. Powertrain technologies

The powertrain is a part of the vehicle that in this paper is defined as follows:

Definition 2.1. The powertrain is the system in a vehicle that generates and transforms the power necessary for propulsion.

The powertrain can be configured in numerous ways. In a conventional vehicle, all propulsion power is always generated in the engine. *Hybrid electric vehicles* (HEVs) are one promising candidate to conventional vehicles. HEVs are in this paper defined as

Definition 2.2. A HEV is a hybrid vehicle including electrical propulsion components. A hybrid vehicle includes a buffer, that can store and deliver propulsion energy, in its powertrain.

One way to categorize HEVs is to use the definitions of series and parallel HEVs. In contrast to a parallel HEV, a series HEV has no mechanical connection between the engine and the wheels. In the series HEV an electric machine handles all tractive torque. Due to the large electric machine of the series HEV, it is suitable for urban driving.³ The good efficiency between the engine and the wheels makes parallel HEVs suitable for highway driving, compared to series HEVs.

The probably most important component in the powertrain is the *primary power unit* (PPU).⁴ The PPU can for example be a combustion engine or a fuel cell.⁵ The PPU converts fuel into power and is defined as

Definition 2.3. The PPU is the power unit, that in a long time frame, provides the majority of the traction power in a HEV. In a conventional vehicle it provides all power.

Fig. 1 shows characteristics of PPUs used in the study presented in Sections 5–7. The figure shows following characteristics of some PPUs of today (2004): fuel cells are efficient but very expensive; batteries are very efficient but have low energy density; and ICEs are the cheapest alternative.

As described in Definition 2.2, HEVs incorporate a buffer. The buffer can for example be a NiMH battery and is defined as

Definition 2.4. The buffer can, in a HEV, provide traction power and store energy.

³The reason is that more braking energy is available in urban driving. A large electric machine enables more regeneration of braking power.

⁴The PPU is important because most losses normally occur in it. The PPU also determines the type of fuel to be used.

⁵It is likely that powertrains with a fuel cell is too expensive in the short term but will be a cost effective option in the long term. Studies in Azar et al. (2002) indicate that hydrogen will be the dominating fuel first after 2050.

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