

A report on payback for vehicle technologies with reduced fuel consumption

Assignment – 4 (11th Feb 2013)



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1 Introduction

The objective of this report is to analyze the benefits of enhancing a baseline vehicle with an SI/CI engine by adding FC reduction technologies in terms of Payback Period (PBP). One of the prime references for developing this analysis is a report by National Academies Press entitled, “Assessment of Fuel Economy Technologies for Light-Duty Vehicles,” National Academies Press, 2011. This report describes a variety of technologies being developed from stand point of Engines, transmission and non-engine technologies. However, this discussion concentrates majorly on engine technologies and transmissions, as non-engine technologies being developed mostly cater to high end vehicles and also, their fuel consumption(FC) reduction potential is observed to be incredibly low. Moreover, the problem statement contains a hypothesis (Table- 1.1) which makes the task of calculating payback period (PBP) less tedious.

Parameter	Quantity	Unit
Cost of gasoline	3.50	\$/Gallon
Price ratio of diesel to gasoline	1.12	-
Baseline fuel economy	28	mpg combined
Vehicle baseline cost	22,000	\$
Interest Rate / Cost of money	4.0	Percent/yr
Increase in cost of fuel per year	4.0	Percent/yr
Miles driven per year	12,000	Miles/year

Table 1.1 Parameters for determination of PBP

The following assumptions can be made from the data for calculating PBP

1. From fuel economy and vehicle base-line cost, it can be assumed that base-line vehicle for this analysis operates on a 4-cylinder, in-line gasoline engine
2. The literature referred to, while calculating the actual technology costs includes only manufacturing cost of the OEM. A retail price factor(RPE) of 1.5 is assumed for SI/CI engines and 1.33 for Hybrid-power trains

3. The fuel economy numbers reported in terms of percentage fuel reduction refer directly to the improvement in mpg when a particular technology is applied over the base-line conditions as previously described

It is worth mentioning at this point that this report does not contain any technical details of the advanced technologies that are being presented and the entire discussion is in terms of reduction levels achieved in fuel consumption in percentage terms when a particular technology is being used.

2 PBP analysis(a)

The level of technologies analyzed in this report can be broadly classified into three categories, namely,

1. Spark-Ignition Engines
2. Compression-Ignition Engines
3. Hybrid Power trains

Technologies studied under Spark Ignition Engines include Valve Event Modulation (VEM) techniques like Intake Cam Phasing (ICP), Dual Cam Phasing (DCP), Discrete Variable Valve Lift (DVVL), Continuous Variable Valve Lift (CVVL), Gasoline Direct Injection (GDI), Turbocharging and friction reduction.

As CI engines have higher mpg values when compared to gasoline engines, most of the technologies studied under CI engines concentrate on calculating benefits of replacing SI engines with CI engines. It has to be noted that replacing an SI engine with CI engine also involves the cost of replacing the fuel injectors, electrical systems and emission control systems. However, the replacement of transmission is clearly indicated when implemented and may not be assumed.

Hybrid power train technologies analyzed include Integrated Starter Generator (ISG) or Integrated Motor Assist (IMA), Prius-type power split, Prius type Plug in Hybrid (PHEV) and parallel Civic hybrid. Series hybrid technology which is widely prevalent in current hybrids is not discussed in this report because the reference does not contain any financial details of this technology.

Table 2.1 represents the discussed details above in terms of numbers

Engine type	Technology	Reduction in FC in percentage	Cost of Technology in USD	Pay-back Period in years
SI	VEM-ICP	1-2%	52.5	3.17
SI	VEM-DCP+ICP	2.5 - 5%	105	2.93
SI	VEM-DVVL	2.5-5%	140	3.28
SI	VEM-CVVL	6-11%	230	2.85
SI	GDI	1.5-3%	300	4.22
SI	Turbocharging+GDI	2-6%	800	4.85
SI	Friction reduction	0.5-2%	66	3.48
CI	Replacing SI with CI(base-level)	25%	2400	6.37
CI	Adding DCT to CI (base-level)	32%	2800	5.76
CI	Replacing SI with CI(adv-level)	33%	2900	5.75
CI	Adding DCT to CI (adv-level)	40%	3200	5.39
Hybrid power trains	ISG 12kW 144 V	35%	2900	4.36
Hybrid power trains	Prius-Type Power Split	40%	4500	5.10
Hybrid power trains	PHEV-Prius	60%	8800	6.11
Hybrid power trains	Parallel Civic Hybrid	45%	7000	6.00

Table 2.1 Table denoting PBPs when different technologies are used

Calculations pertaining to PBP are presented in terms of a MATLAB code in the appendix.

From the table,

- FC reductions in the case of SI engines are presented as a min-max range as the numbers are quite small and can change drastically for different types of engine technologies. For analyzing the set of base-line conditions prescribed for this analysis, minimum of these numbers is used to calculate PBP. This is also justified by the fact that 4-cylinder Inline configurations usually support very small improvements in fuel economy when compared to other configurations
- It can also be seen that most of the technology (SI) is being improved around Valve Event Management and it also has a very high sales potential because of very low PBP(around 3 years)
- Pertaining to CI engines, it can be seen that they have a very high FC reduction numbers but they also come at a considerable cost with PBP's at around 6 years. Most newly owned cars enter their second ownership phase by this period

- Other major issue with adopting CI engines is compliance to emission standards. Diesel available in the US contains very high quantities of Sulfur (~15 ppm) which interferes with the working of the emission control
- CI engines usually have higher torque values when compared to SI engines. Hence, it is advisable to use a downsized engine with an advanced transmission system like Dual Clutch Transmission (DCT) to enhance the efficiency of the system. Although this adds to the cost, it reduces the PBP
- In case of hybrid power trains, it can be clearly seen that their PBPs are currently the highest at more than 6 years for almost all the technologies. This is one of the reasons for their not very impressive impact on the current market
- However, it has to be realized that hybridization is extremely relevant and fruitful for urban drive schedules because of the potential for regenerative braking. Hence the PBP numbers can be lowered at least by 0.5 years based on drive cycle
- Problem with PHEV's is that it takes long intervals of time for the battery to get recharged. For example, it takes around 5 hours to recharge a battery capable of doing 200 miles in city conditions
- ISG/IMA seems to be an optimistic investment as it has a moderate cost of investment for a decent PBP of four years

3 Comprehensive Bubble chart analysis (b & c)

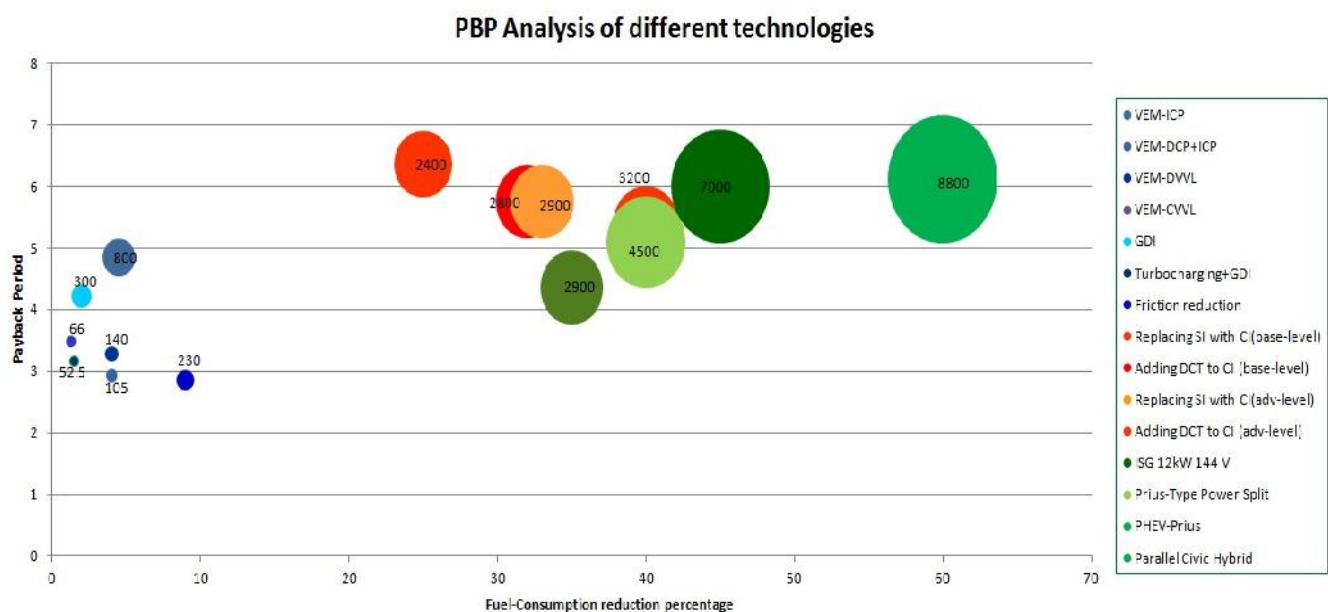


Figure 3.1 Graphical representation of PBP analysis

Figure 3.1 is a graphical representation of the Table 2.1 and presents a convenient method to analyze the numbers presented in the table. The x and y axes represent the reduction in fuel consumption and pay-back period respectively. The diameter of the bubble represents the cost of technology. The color coded bubbles also have a visual logic which needs to be realized as follows

- All the shades of blue present information pertaining to **SI engines**
- All the shades of red present information pertaining to **CI engines**
- All the shades of green present information pertaining to **Hybrid technologies**

From the bubble chart, (especially part C)

- From a PBP standpoint, it is desirable to have a smallest bubble, as close as possible to the x-axis
- Hybrid technologies clearly lose the race as they are represented by largest bubbles and are farthest from x-axis with highest PBPs
- However, in terms of FC reduction, Hybrid Technologies have the maximum potential (about 40%) and SI engine technologies have a minimum potential of 2-5%. This means that most OEMs must concentrate on diminishing the cost of technology which automatically lowers PBP
- CI engines are in a sort of a middle ground in terms of FC reduction potential, but have a relatively high PBP. This can be realized from the fact that the cost of technology in this case is moderately higher when compared to the other two technologies
- SI engines have very good PBPs averaging around 3.5 years. Also the fact that most of the technology enhancement is relatively inexpensive and that infrastructure for automobiles in the US is developed around gasoline engines, makes it is easier for OEMs to adopt to these technologies
- But, considering long-term impact, it is better for OEMs to develop their technologies around hybrids, as there they posses maximum FC reduction benefits (around 50%)

4 PBP analyses for Europe (d)

The analysis for the European markets has been done by considering 1EUR = 1.3USD and 1US gallon = 3.8 liter.

Engine type	Technology	Reduction in FC in percentage	Cost of tech in Euro	Pay back for Europe in years	Pay back for US in years
SI	VEM-ICP	1-2%	40	2.24	3.17
SI	VEM-DCP+ICP	2.5 - 5%	81	2.10	2.93
SI	VEM-DVVL	2.5-5%	108	2.31	3.28
SI	VEM-CVVL	6-11%	177	2.20	2.85
SI	GDI	1.5-3%	231	3.42	4.22
SI	Turbocharging+GDI	2-6%	615	3.94	4.85
SI	Friction reduction	0.5-2%	51	2.45	3.48
CI	Replacing SI with CI(base-level)	25%	1846	3.23	6.37
CI	Adding DCT to CI (base-level)	32%	2154	3.22	5.76
CI	Replacing SI with CI(adv-level)	33%	2231	3.22	5.75
CI	Adding DCT to CI (adv-level)	40%	2462	3.15	5.39
Hybrid power trains	ISG 12kW 144 V	35%	2231	3.05	4.36
Hybrid power trains	Prius-Type Power Split	40%	3462	3.47	5.10
Hybrid power trains	PHEV-Prius	60%	6769	4.14	6.11
Hybrid power trains	Parallel Civic Hybrid	45%	5385	4.08	6.00

Table 4.1 Chart denoting PBPs for Europe

The following can be interpreted from Table 4.1 and Figure 4.1

- There is no particular difference in the trend followed by PBP across different technologies between Europe and US
- However, PBP of CI engine technologies in Europe are a bit on a lower side when compared to PBPs in US. This can be attributed to the fact that the average fuel cost in Europe is slightly higher than that in US

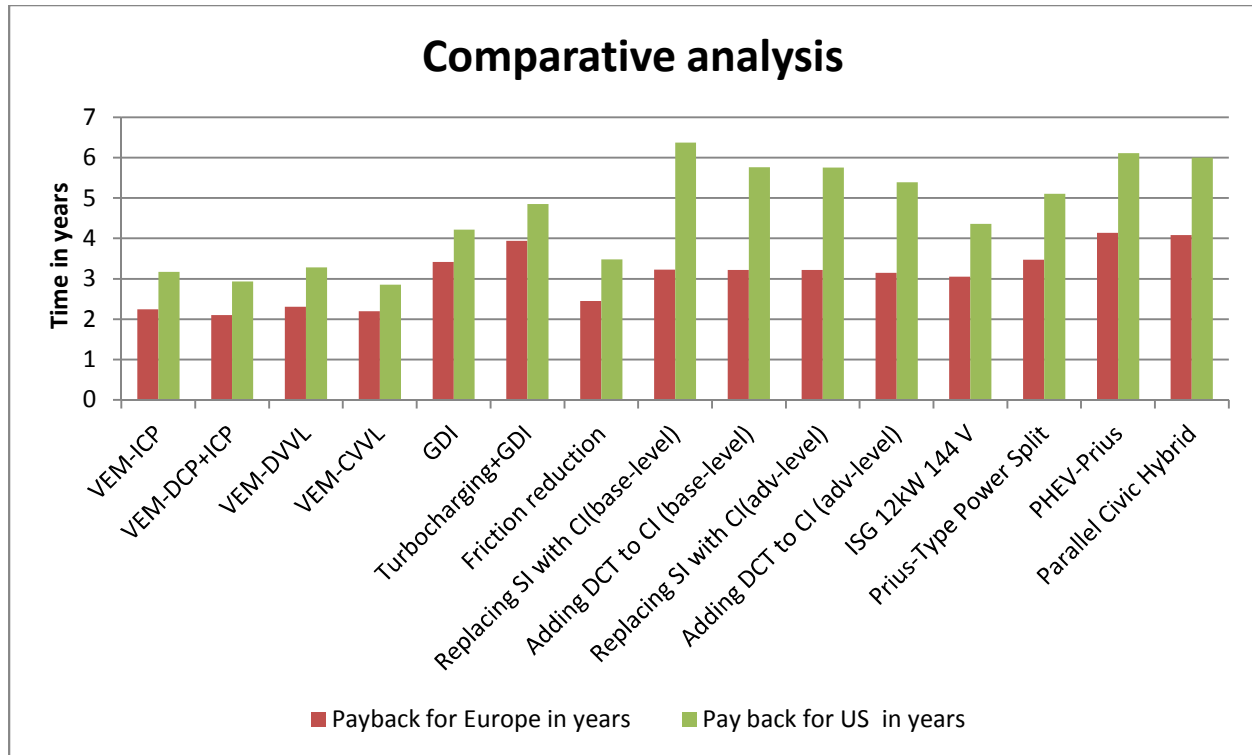


Figure 4.1 Graphical representation of comparative PBP analysis

5 Conclusions (e)

The following conclusions can be made from the analysis

- Gasoline engine technologies have the least PBPs by far but they do not have drastic improvements in Fuel Economy
- In terms of maximum FC reduction, Hybrid technologies seem to be very promising but their cost has to be reduced before their merits are realized in PBP terms
- CI engines also possess a considerable potential for FC reduction but in US, technology is not fully developed for light duty CI applications. Moreover cost of diesel is slightly higher than gasoline
- It can be assumed that FC reduction technologies will majorly concentrate on gasoline engines because of the available infrastructure and least cost of technology
- Most OEMs do not concentrate on reducing accessory load because FTP drive cycles are not built around testing mpg of vehicles with accessory loads

6 References

1. Committee Report, "Assessment of Fuel Economy Technologies for Light-Duty Vehicles," National Academies Press, 2011
2. Hymotion Prius PHEV Demonstration Summary Report, Idaho National Laboratory, 2011

7 Appendix (PBP calculation procedure) (f)

The payback period PBP is defined as the time taken for the recovery of the cost of technology. Recovery is attributed to the increase in mpg or decrease in fuel consumption because of the technology itself. However, it has to be realized that the cost of gasoline is also not a constant and varies at (estimated 4%) a year. Also, the cost of money diminishes at a rate of (estimated 4%) a year.

Algorithm

- Declare variables with initial values. They include cost of gas, interest on gas per year, miles driven per year, cost of money, baseline mpg, improved mpg and cost of technology
- Start loop(loop counter is number of years), calculate the cost of gas after 1 year, also the diminished value of \$1 after 1 year
- Calculate the difference of expenditure (gain) with old mpg and improved mpg and multiply this with the diminished value of 1\$
- If cumulative gain < the cost of technology then repeat from step 2
- If cumulative gain > the cost of technology, terminate loop
- From the gain of last iteration, and the difference of the cost of technology from the cumulative gain, calculate a factor difference/gain and add it to the loop counter
- The final step provides the correct value of payback period in years

MATLAB code for the algorithm above is provided below. This is a sample calculation for Prius type power slip with cost of technology of 4500 and an mpg factor of 1.4 (40% improvement in mpg)

```
clc;
clear all;

cost_gas = 3.5; %per gallon
int = 4; %cost of money per year
int_gas = 4; %interest rate of gas
miles = 12000; %miles driven per year

invested = 4500; %initial cost of technology in USD. This is a variable and depends
on technology used
```

```

mpg = 28; %when gasoline is used
imp = 1.4; %mpg improvement on new technology
new_mpg = 28*imp; %mpg enhancement factor due to new technology - variable

%Iterations for calculating pay-back

year = 1;
return1 = 0;
return_iter = 0;

while return1 <= invested
    cost_gas = cost_gas*(1+int_gas*0.01);
    p_value = 1/((1+int*0.01)^year);
    gas_spend = (miles*year)*(1/mpg)*cost_gas;
    gas_spend_new = (miles*year)*(1/new_mpg)*cost_gas;
    return_iter = (gas_spend - gas_spend_new)*p_value;
    return1 = return1 + return_iter;
    deficit(year) = invested - return1;
    year = year+1;
end

pbp = (year-1)+(deficit(year-2)/return_iter); %Payback

```

END

Grade Sheet

Student Name: Arjun Darbha.

Area	Points	Score
Cover Sheet	5	
Introduction	5	
Sections A-F		
Discussion of Results – These must be quantitative	30	
Tables and Figures including formatting	40	
Summary and Conclusions	10	
Following format and instructions for report and submission	10	
Total =	100	