Hybrid Vehicle

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***Abstract;-* This briefing paper is a technical summary for policy makers of the status of hybrid vehicle development in the United States. Both sales of hybrid vehicles and the number of hybrid models have risen steadily in the U.S. since their introduction, with that growth trend accelerating sharply starting in 2003. The forty-five hybrid models available in 2014 captured about 2.75% of the overall U.S. passenger vehicle market, down slightly from 3.19% in 2013. For purposes of comparison, hybrid market share is about 6% of vehicles sold in California and about 20% in Japan. At their present state of development, full-function hybrids reduce fuel consumption by 25 to 30 percent, at a manufacturing cost increment of roughly $2,500 to $3,500. While mild-hybrid systems, such as belt- alternator or 48-volt (48v) systems, are not as efficient, their cost-benefit ratio can be better because they are less than half the cost of full-function hybrids.**

Keywords—Development, fuel consumption cost, efficient

I. INTRODUCTION

This is the first in a series of technical briefing papers on trends in energy efficiency of passenger vehicles in the United States. The series was conceived with the aim of summarizing technology developments relevant to passenger vehicle efficiency policy in the U.s. Simultaneously reducing costs, increasing vehicle size, engine power, and electric motor power, and multiplying consumer features. The purple line in figure 1 illustrates reductions in pries hybrid system cost based upon changes in the motor propulsion system and the pries list price versus the price of a comparably equipped corolla, without considering efficiency improvements. costs fell almost 5% per year from 2000 to 2010, right in line with the rate of reduction from 2010 to 2013 (green line) as determined by the consultancy Fey.

TABLE1

	prius mSrp	$ prius / corolla le	price increase	icm	cost increase
Prius 2011	$23,520	1.34	Base		Base
Prius 2004	$20,295	1.37	$454	1.56	$291
Prius 2001	$19,995	1.49	$2,238	1.77	$1,265

are in much earlier stages of engineering development can replicate that rate of improvement, full-function hybrid system costs will be cut in half before 2025.

FUEL CONSUMPTION REDUCTION

Hybrid systems can reduce fuel consumption and co_2 emissions by up to 35%, equivalent to more than a 50% increase in fuel economy.[7] The precise reduction varies with the sophistication of the hybrid system. The reduction can also be difficult to quantify if there is not a directly comparable non-hybrid vehicle. This second point is illustrated by the most comprehensive study to date, an October 2014 analysis done by the consultancy vincentric, which compared 31 hybrids to the closest non-hybrid vehicle.[8]

The vincentric hybrid Analysis provides a direct comparison of the efficiency benefits and costs of hybrid systems. For any individual model the difference in efficiency between the hybrid model and the non- hybrid comparable may be affected by differences in power train, weight, tire rolling resistance, and aerodynamic drag. For example, all of the Toyota hybrid systems are similar, yet the calculated fuel consumption

CURRENT HYBRID COST ESTIMATES

It is even more difficult to determine precisely the cost of hybrid systems than the efficiency benefits they confer. hybrids are often bundled with consumer features and options that have a far larger impact on vehicle price than on efficiency. Also, prices charged by manufacturers are set in a highly competitive market and may not reflect the real cost of the hybrid system. The tear-down method has four advantages:

TABLE2

1. All hybrid components were

	input power-split	p2 hybrid
Power transmission/clutch system	$608	$300
Integrated electric motor/generator/ sensors/controls	$1,518	$675
Li-ion Battery Subsystem (1.0 kWh)	$1,375	$1,375
Electricity power distribution, inverters/converters	$379	$379
Brake, body, climate control systems	$461	$461
Credits – transmission, engine, service battery, alternator	-$1,217	-$276
Total	**$3,122**	**$2,912**
costs adjusted from 1.4:1 to 1.15:1 dollar/euro	**$2,565**	**$2,392**

accurately identified and costed.

2. Consistent methodologies and assumptions were applied.
3. Costs were assessed directly, rather than being inferred from price.

PAYBACK PERIOD

The payback, in terms of fuel savings versus hybrid price premium, calculated for each hybrid vehicle from the data in the vincentric analysis. The results vary widely from vehicle to vehicle, for the reasons noted above. currently, roughly 29% of hybrid models (9 out of 31) pay back the initial hybrid price premium with fuel savings within 5 years. roughly 61% of hybrid models (19 out of 31) pay back within the full useful life.

1 The 2017-25 Joint Technical support document cost estimates were $2,463 for a p2 hybrid and $3,139 for a power-split hybrid in 2017, suggesting that the agencies see more potential for future cost reduction for p2 hybrid systems.

2 The vincentric report did not state what fuel price they used for their analysis.

IAMPACTSOFLEARNINGAND IMPLICATIONFORFUTURE HYBRID DEVELOPEMENT

The Toyota prius hybrids have delivered about a 10% efficiency improvement with each new generation, while simultaneously reducing costs, increasing vehicle size, engine power, and electric motor power, and multiplying features (table 2 and figure 9). This was accomplished primarily by learning. Toyota built upon the best features of each design to improve the next design, with both better hardware and better integration and control of the various hybrid components. These improvements were delivered while reducing the price of the prius relative to that of the corolla 1e.

HYBRID SYSTEM IMPROVEMENTS IN DEVELOPMENT

hybrids, especially the p2 and lower-cost hybrid systems, remain at a relatively early stage of development. seamlessly integrating engine, electric motor, battery, and regenerative braking functions is complex and difficult, requiring sophisticated simulations in the development process and powerful onboard computers to avoid drivability problems. one factor in the early success of the input power-split hybrid is that the planetary gear system helps to smooth out the transitions between the different power sources and reduces the development burden. Honda's early iMA system similarly reduced the development burden by bolting the motor directly to the engine. Unfortunately, as discussed earlier, the input power-split is a relatively expensive solution, and the iMA system is not competitive on benefits and costs with newer systems.

1ess expensive hybrid systems will benefit greatly from the ongoing revolution in computer simulations, computer-aided design, and on-board computer controls. indeed, the revolution in computers is essential to development of lower-cost systems with good drivability. This section outlines some of the more promising improvements that have recently emerged: batteries with higher power density, design improvements for p2 hybrids, and lower-cost 48v hybrid systems. A more extensive discussion is presented in appendix 3.

IMPACT OFWEIGHTREDUCTION ON COST

It reducing vehicle weight means that the power train can be downsized and still maintain constant performance. This applies directly to the electric motor propulsion system. A 10% reduction in weight will allow a 10% reduction in the electric propulsion motor and all supporting hybrid system component.Fev's baseline costs of $3,122 for the input power-split hybrid system in table 1 were for a European midsize car with a 78 kW motor. Thus, a 10% weight reduction would reduce the motor size 7.8 kW. Using the cost derived above for table 4 of 14.15 Euros per kW, the cost of the hybrid system would be reduced by $155, or about 5% of the total cost of the hybrid system.

AUTHORS AND AFFILIATIONS

Hybrids are far from a mature technology, and innovations and improvements are coming rapidly. improved batteries designed with high power density for hybrid applications will start arriving soon. hybrid systems other than the input power-split design pioneered by Toyota 17 years ago are still in early stages of development, and present huge opportunities to reduce cost through better designs, learning, and economies of scale.

The purple line illustrates the estimated reductions for each new generation of the prius (note that the 2001 model was introduced in 2000 and the 2011 model in 2010). The green line reflects Fev's 15% cost reduction for the power transmission/clutch/ motor subsystems from 2010 to 2013, assuming that the same reductions are achieved in all parts of the hybrid system. The lighter dashed blue line projects future p2 hybrid system costs assuming that the 5% annual cost reduction continues into the future.

DIFFERENT HYBRIDSYSTEMS

1. INPUT POWER-SPLIT. As its name implies, this system uses a planetary gear to distribute power between the engine, generator, traction motor, and drivetrain. it is the most sophisticated of all the currently available hybrid systems and excels in optimizing engine efficiency during city driving. it is also easily adaptable to plug- in operation.

2.TWO-MOTOR SYSTEMS. These are similar to the input power-split system in that part or all of the energy for the traction motor is provided from the engine through the generator, but they do not use a planetary gear system to transmit power. Two-motor systems offered in the past by gM, chrysler, BMW, and Mercedes had similar, if not better, efficiency than the input power-split, but at higher cost. All have been discontinued. honda recently introduced a two-motor system on the 2015 Accord, which captured 3% of the hybrid market in 2014.

PARALELL HYBRID WITH TWO CLUTCHES (P2).

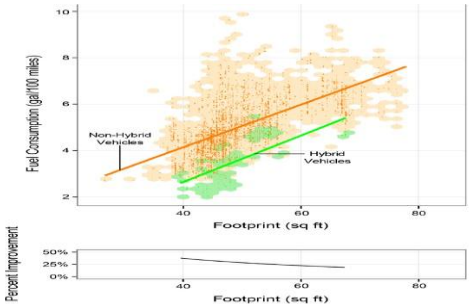
Uses a single electric motor and two clutches, one between the engine and the electric motor and the second between the motor and the drivetrain. This system is highly scalable, from modest electric motor power to motors capable of plug-in hybrid operation. different variations of this system have been recently introduced by nissan, hyundai/Kia, vW/Audi/porsche, subaru, BMW, and Mercedes. hyundai/Kia is by far the leading seller of p2 hybrids, with 8% of total 2014 hybrid sales.

MILD HYBRIDS. “Mild” hybrid is an undefined term loosely applied to hybrid systems that do not have all of the capability of full-function hybrids, such as the two-motor systems and the p2 hybrid, but have more functionality than stop-start systems or micro-hybrids. BAs systems and honda’s iMA system are examples of mild hybrid systems. new concepts using 48-volt hybrid systems are in development and often include a small, electric motor integrated into the turbocharger to eliminate turbo lag and allow additional engine downsizing.

MICRO-HYBRIDS.

In addition to stop-start, provides limited amounts of regenerative braking energy and some additional functions, such as providing energy to replace most of the alternator functions, and shutting the engine off and disconnecting it from the drivetrain during higher speed decelerations (commonly called “sailing”). The system also provides faster engine restarts with less vibration than conventional starters. Many different types of micro-hybrids are being developed, from 12v systems using advanced lead-acid batteries to 12v or 24v systems assisted by small ultracapacitors or using niMh or li-ion batteries. The first production micro-hybrid system is Mazda’s i-eloop, which was introduced in 2014 on the Mazda3 and Mazda6. it uses an ultracapacitor to capture a limited amount of regenerative braking energy and provide power for conventional vehicle electronics in place of the alternator.

GRAPH:



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