The evolution of powertrain technology 2008 and beyond: engines, hybrids, battery electric, fuel cells, transmissions

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ABSTRACT

An ever-increasing number of factors are forcing change upon the light-duty vehicle powertrain. With limited investment funds, OEMs and suppliers alike are hard-pressed to decide in which technologies they should invest, and to project the magnitude of the likely returns on those investments. To help put these investment decisions in context, DRI-WEFA and TIAX teamed together to examine the future of powertrain technologies. This study addresses the technical and business issues related to the evolution of the engine and transmission, the barriers that must be overcome to meet future goals, and the developments that will be required to overcome such challenges. To ensure that the conclusions are robust, this study also assesses the sensitivity of the forecast to changes in the economic, energy and business environment.

Three possible scenarios for economic, energy, and business environment are developed for the 2008 to 2020 time frame. The future fuels, technology barriers and enablers, and the commercial aspects of possible evolutionary as well as revolutionary powertrain options were then discussed with traditional automotive suppliers, developers of new powertrain technologies, energy companies, and automotive manufacturers. A thorough analysis of their answers yielded scenario-specific forecasts along with the rationale behind them.

This paper highlights the methodology and the top-level conclusions of this comprehensive study. As such, this paper provides a brief overview of a forecast built upon numerous, more detailed analyses, which will provide direction and guidance to industry strategists, planners, and investors as they place their bets on future powertrain technology.

1 INTRODUCTION

1.1 Background

The scope of this DRI-WEFA/TIAX study was based on conversations with a number of automotive clients. These firms, most of them suppliers to the vehicle manufacturers (OEMs), see a proliferation of technologies in the powertrain area. However, they recognize that they do not have the resources to fully explore every technology. Conversely, they also recognize that they cannot afford to be left out if an alternative technology should gain significant market share. Only a few technologies will lead to significant long-term business, as future powertrain technologies may move away from those in a particular area. Knowing which products are on a development path that will lead to large market shares is critical in deciding on appropriate levels of funding for each product opportunity.

1.2 Objectives

The objectives of this study, therefore, are to provide automotive suppliers and OEMs with:

1) A set of plausible alternatives that cover the likely range of future market, crude oil price, regulatory and business environments that will drive demand and enable development of future powertrain technologies.
2) An assessment of the expected benefits and costs of various powertrain technologies that are under serious consideration for the future.
3) Identification of the respective technical and/or market barriers, if any, that must be overcome to bring those technologies to market, and hence an identification of possible business opportunities (or threats) with respect to future powertrain technologies.
4) A forecast of the market share of these technologies in the 2008 to 2020 time frame to guide current investments, capital planning, and product portfolio development of the OEM and supplier community.

1.3 Methodology

The basic premise of this research is that the future likely fuel prices and regulations will fall within reasonable, predictable bounds. Within these bounds, it is possible to assess the desirability of each technology by looking at its benefits, costs, and market appeal relative to the spark ignition engine and its strong challengers such as the direct injected Diesel. Building upon this premise, the program objectives were addressed in a straightforward, stepwise manner, and based on an objective mathematical model of the market for future powertrain technologies. The methodology incorporated a number of sequential steps:

i) Scenario Development Three alternative scenarios (Baseline, Easy Street, and Rough Ride) were developed for future crude oil price and availability, emissions and fuel economy (or CO_2) regulations, and economic outlooks. The latter included vehicle production volumes and the cost of money in Japan, Western Europe (using the "big four" as a surrogate) and North America (using the U.S. as a surrogate).

ii) Vehicle Use Patterns And Trends These were studied to determine if there is any indication that a major shift in vehicle use might impact the competitive position of, or need for, various powertrain technologies. For years, regulators at the national and local level have tried to address air quality issues by encouraging the use forms of transport other than the personally owned motor vehicle. For such changes to have a major impact on the characteristics of personal vehicles and their powertrain technologies by 2020, at least the beginnings of such trends would have to be observable now. We looked for those recent trends.

iii) Technology Assessment Our resident experts generated position papers on internal combustion engines, exhaust gas treatment (catalytic oxidation and/or reduction and particulate reduction), alternative fuels, transmissions, hybrid- and battery-electric vehicles, and fuel cells. These papers assessed the technical and commercial readiness of these technologies to address the regulatory and market demands of each scenario. In-house knowledge was supplemented with in-depth discussions with automotive industry personnel as necessary to round out the knowledge base of these papers, which were then reviewed by other industry figures. These reviews resulted in a series of issues being raised about each technology. The results of these position papers, modified as necessary to reflect the findings of our research, are summarized briefly in this paper.

iv) Analysis And Industry Feedback A powertrain model, built using the commercially available software package GT-Drive ™, was used to estimate the fuel consumption performance of various powertrain technologies in vehicles typical of those in each major segment over the European, Japanese, and U.S. Federal Test Procedure (FTP) drive cycles. The benefits and limitations of each technology were entered into a custom market share model developed for Western Europe, North America, and Japan. This activity raised further issues with respect to each technology and the industry's deployment of them.

These issues were then discussed with industry personnel at over 50 companies in Western Europe, Japan, and the United States. As a result, our understanding of the viability and desirability of each technology and the likely evolution of the technology was enhanced, and our knowledge of the "soft" issues such as the sourcing of future powertrains was expanded.

v) Key Findings And Conclusions A refined market share model was developed for each scenario and region and used to forecast the market share of each technology.

Given the breadth and depth of this study, it is not possible to report here all of the details that led to the final analysis. Instead, only a fraction of the study is touched upon in this paper, which presents the forecast on a global basis. A complete breakdown of the global forecast into Western Europe, Japan, and North America along with the full details of the study are reported in reference [1].

2 KEY FINDINGS AND CONCLUSIONS

Improvement of vehicle fuel economy remains one of the critical challenges facing powertrain engineers. There are many ways to improve fuel efficiency of conventional reciprocating engines (both SI and Diesel). The auto-industry will continue to pursue a combination of many of these evolutionary approaches starting with the most cost-effective and increasingly employing more expensive concepts over time.

Alternative powertrains (as exemplified by fuel cells, continuous combustion systems, rotary engines, and two-stroke engines) have some key strengths, but on balance are not expected to be competitive with the IC engine through 2020.

2.1 Alternative scenarios

Three alternative scenarios representing plausible, yet different, futures have been developed. The scenarios developed cover a range of reasonably likely alternative futures that test the sensitivity of powertrain technologies to plausible future events. These scenarios are:

- Baseline: A base-case scenario – the study team's best estimate as to the most likely future scenario (>50% probable).
- Easy Street: A scenario in which the emphasis is on reduced particulates, but in an environment of low cost fuel and a robust global economy (not unlikely alternative scenario, judged less than 50% but more than 20% likely)
- Rough Ride: A scenario in which reductions in fuel consumption (CO_2) and particulates must be accomplished in a constrained global economy and high crude oil prices (an upper difficulty bound, judged at least 10% probable that regulatory and global economy conditions will be at least this challenging).

The factors used to construct each of these scenarios are shown in Fig. 1.

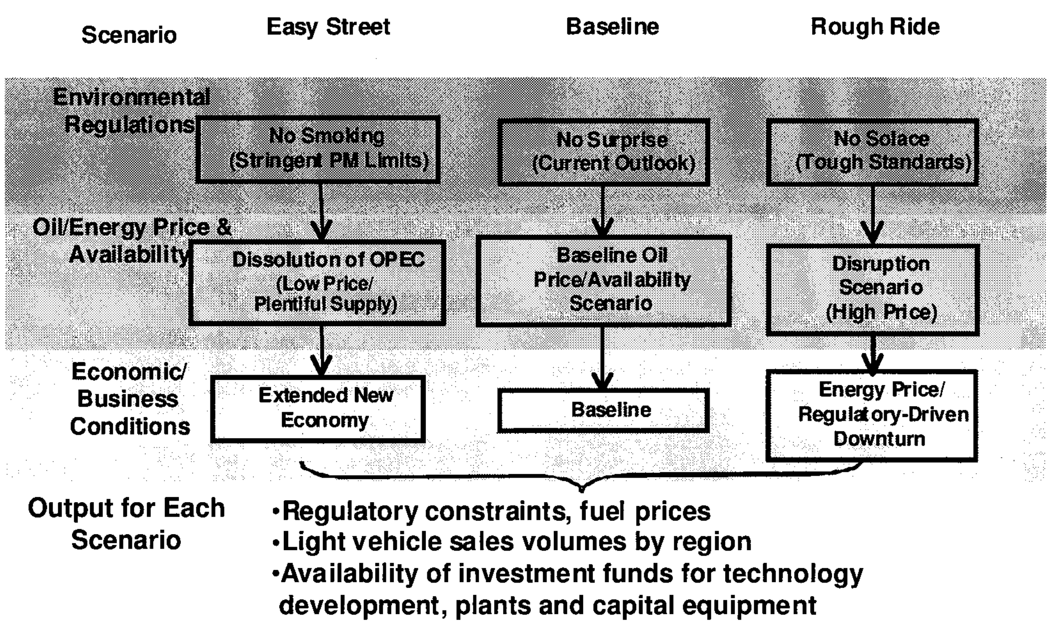

Fig. 1 Elements of the alternative scenarios

A fourth regulatory scenario, "No Guzzling," could also be constructed. In this scenario substantial reductions in CO_2 are required, but particulates are not further restricted. We believe, however, that such a scenario is unlikely because the health effects of particulates are well known and a current major focus of regulators. Furthermore, the sensitivities of powertrain technologies to more stringent reductions in CO_2 are adequately tested under the Rough Ride scenario.

2.2 Vehicle use patterns and trends

An analysis of several statistical and historical trends was used to determine future trends in personal vehicle use. As indicated above, for changes in vehicle use characteristics to have a significant impact on powertrain technologies by 2020, such trends would begin to be observable now. Despite over four decades of societal awareness of the ecological and political impact of the use of fossil fuel burning vehicles for private transport;

- There are no trends to indicate that a major shift in vehicle use will occur through 2020. Despite increased congestion, use trends in all 3 regions show that the use of personal motor vehicles increases while patronage of public transport is decreasing or holding steady except for light rail in Japan.
- Vehicle power to weight ratio is increasing in all regions, indicating a consumer preference for increased acceleration and/or hauling capacity.
- Legislation to promote alternative transportation or car-free zones may limit or prohibit the use of vehicles in congested city centres, but there is no evidence to support the forecasts that this will have a profound impact of the sales of more conventional vehicles, on personal vehicle performance or powertrain technologies in more conventional vehicles.
- Zero emission vehicles are likely to take the form of low power electric vehicles for use in controlled neighbourhoods such as retirement communities, or cooperatively or corporately owned fleets for the purpose of car-sharing in downtown (city centre) areas.

Vehicle characteristics: safety overrides energy efficiency: there is reluctance to reduce weight and incur a safety penalty

- Weight reduction will be one of the most important ways to achieve the fuel efficiency (CO_2) and in some cases the emissions reductions required for some vehicle segments.
- In the United States, these reductions are most significant for the light trucks that have until now been largely body on frame construction (Pickups, some full size vans, and large SUVs).
- In Europe and Japan there is less scope for such profound weight reduction and the segmentation is such that reduction in the weights of the heavier segments will have much less impact on the overall fleet-average fuel consumption.
- Meeting the Baseline scenario in Europe requires an acceleration of the segmentation shifts towards smaller cars that are already forecast from 2001 to 2006, and a reversal in the popularity of the minivan back to smaller cars.
- Even more profound shifts in market segmentation are needed to meet the Easy Street Scenario should there be an emissions-driven phase out of the Diesel in this scenario

Aftertreatment will determine what may be built: fuel consumption will determine what will be built

- The port injected, stoichiometric spark ignited engine with so-called three-way catalyst exhaust treatment is and will continue to be the "best available control technology," and will be the benchmark by which emissions from other engines are judged.
- Of the alternative engines, HCCI (CAI) and lean port injected engines have exhaust characteristics that are easiest to treat
- The high speed diesel is most at risk, and will need exhaust aftertreatment breakthroughs under severe particulate and NOx scenarios

- All engines will come under increasing scrutiny for toxins - Diesel is most at risk under this category as well

Improved gasoline engines could retain ~1/2 the global market by 2020

- The baseline spark ignited engines will improve fuel consumption, on average, ½% per year between 2008 and 2020. These improvements will come from evolutionary developments in friction reduction, manufacturing improvements, mass reduction, improved management, etc. as well as the application of technologies such as those discussed below.
- Despite improvements in friction reduction, manufacturing, etc., the Diesel will exhibit much less improvement in overall fuel efficiency due to the increases in fuel consumption required to effect exhaust gas treatment of NOx and particulates. Nonetheless, the Diesel will remain the most efficient internal combustion engine through 2020.
- Diesels continue to gain share where emissions regulations allow it.
- DI gasoline engines, combined with some vehicle segmentation shifts, are promising to enable future fuel efficiency mandates to be met if toxicity issues rule-out the diesel, but cost and emission improvements will be needed for GDI, especially when operated in stratified form.
- Alternative technologies are not required, but could reduce or eliminate need for segmentation shifts
- Fuel Cells: Provided there is successful technology development and manufacturing cost reduction, we may see start of commercial inroads towards the end of the forecast period.
- ZEV: Not substitutes for more conventional light vehicles for several reasons including continued range limitations and rate of recharging.

Table 1 Most likely power unit shares in 2020

Global Market Share of Engine Technologies: 2020

	Conv. SIE	Adv SIE	GDI	HSDI
Baseline	52%	13%	10%	25%
Easy Street	51%	22%	26%	0%
Rough Ride	7%	24%	69%	0%

The Transmission will become an active part of the engine management system

- The transmission will dictate the engine speed at which the required power is delivered, optimising the trade-off between emissions and fuel consumption.
- Automated or robotized manual transmissions will give way to wide ratio fully automatic transmissions that shift without torque interruption to improve emissions and the acceptability of the automatic transmission. Where no major automatic transmission infrastructure now exists, these fully automatic transmissions are likely to be based on dual-clutch countershaft designs due to their inherently better efficiency.
- The CVT, due to its inherent inefficiencies, will be used only in those duty cycles where the powertrain load trajectory is highly variable, and hence independent control of engine speed can yield significant benefits that more than offset the increased losses in the transmission.

Hybrid vehicles including those with stop/start will play a major role in meeting future standards

- By 2020, over half of all light vehicles have some degree of hybridisation, including stop-start.
- Hybridisation is driven primarily by fuel consumption related issues, not emissions
- Full-hybrids enjoy only a relatively small market share even under very stringent (Kyoto-level) fuel consumption scenarios

Table 2 Most likely global market shares of various levels of hybridisation in 2020

	14-V	42-V[1]	micro-HEV[2]	Mild-HEV[3]	Full-HEV[4]
Baseline	0%	33%	58%	6%	3%
Easy Street	0%	32%	57%	7%	4%
Rough Ride	0%	5%	37%	46%	11%

3 SUMMARY CONCLUSIONS FOR 2020

- Significant gains in fuel efficiency can be achieved while retaining the current investment in engine technologies.
- Port fuel injection and direct fuel injection engines, both gasoline and diesel, are most likely to continue to share the global marketplace.
- Current levels of vehicle mobility, versatility and safety can be retained while significantly improving emissions and fuel efficiency in the US and Europe:
  - 90 and 80 % respective particulate reduction
  - 26 and 29% respective fuel efficiency improvement
- Simultaneous, extreme but plausible levels of fuel efficiency and tailpipe emissions standards may be disruptive, requiring regulatory trade-offs between air quality, energy dependency and global warming

REFERENCES

[1] DRI-WEFA and Little, A.D (Dec 2001), Future Powertrain Technologies, the Next Generation

[1] On-board power generation at 42-volts enables better management of parasitic loads, reducing fuel consumption up to 10% or more.
[2] 42-volt system with stop/start operation only. No launch assist
[3] Stop start and mild assist. Electric motor power less than 1/3 that of the ICE
[4] Electric assist over a substantial portion of the duty cycle. Electric motor power about equal to that of the ICE