Hybrid vehicles provide a glimpse of the future of environmental vehicle design (e.g., Toyota, Honda, and PNGV), but what is needed to succeed in the marketplace?

Factors limiting hybrid market potential as well as near-term production prospects are discussed in this paper. The objective is to understand the barriers to introducing hybrid technology and the necessary ingredients to succeed in what will be a dynamic and competitive environmental vehicle market.

These views are based on integrating the results of our ongoing global technology assessment with analyses of the economic factors affecting the production and sale of hybrid vehicles for the International Energy Agency (both sponsored by the DOE Office of Advanced Automotive Technology).

Competition Limits Potential

The market potential of hybrid vehicles is limited by tough competition from conventional vehicles, which are relatively inexpensive and widely available. Refinement over the years has resulted in vehicle quality being higher than it has ever been. Reliability and durability of today's IC engines is proven and customers are equally comfortable driving across town or across the country.

Conventional engine technology has not been stagnant while hybrid concepts were being developed; in fact, leading manufacturers have produced mainstream vehicles that honestly can be considered "environmental" vehicles. The best example is the Honda Accord EX that meets California's SULEV standard. Overall performance of the vehicle population has improved as well. Ignoring the passing trend of buying larger and larger SUVs, fuel consumption and emissions of typical cars have decreased with each model introduction.

Relevant Engine Development

Since IC engines are important to the success of hybrids as well as conventional vehicles, engine developments are relevant to market potential.

The near term development that will have the most impact on the industry and hybrids over the next 5 years is the Integrated Starter-Alternator Damper (or ISAD), which replaces the flywheel on the crankshaft. These units can provide engine cranking and generate electrical power in addition to damping engine torque variations.

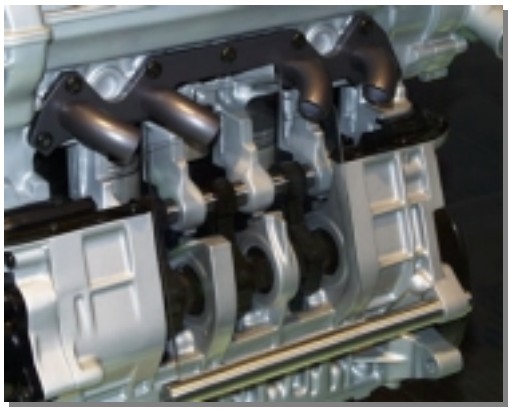
ISAD technology allows the engine to be turned off when it would normally idle and can supply power assist during acceleration or recover energy while braking (i.e. in a parallel hybrid configuration). Large suppliers, such as Siemens and Continental/Delco Remy, plan to produce millions of the units annually. This physical configuration is common to several parallel hybrid concepts developed over the past decade, but the most recognized (similar) implementation is now in production - the Honda Insight.

Direct injection is common, but high pressure direct injection (HDI) is just getting into production (e.g. Siemens), but the long term effect of smaller exhaust particles on our respiratory systems is now in question.

Variable valve timing is becoming common as well and the potential for precise control of electromechanical valve actuation is an even more attractive feature for engine developers. However, these systems require high power for fast response – an usually high demand for belt-driven alternators. A developmental system by BMW is shown in the photo.

There will be few diesels without turbochargers (especially large engines) and variable turbocharger boost will be widespread.

Several methods are being developed to vary the expansion/compression ratio of engines, but the latest is the Saab Variable Compression (SVC) engine (shown at the top of the page). The engine block and head are hinged and the combustion chamber volume is varied by tilting the head, resulting in a continuously variable compression ratio



from 14:1 to 8:1, allowing supercharging without knocking.

NOx catalysts are under development by several manufacturers/suppliers.

Appropriate combinations of these technologies will improve fuel economy and emissions by 20-40%.

Hydrogen may be the long-term solution to emissions. Addressing this issue is beyond the scope of this discussion, but a question arises relative to engines. Are they better converters of hydrogen energy than fuel cells from a systems perspective (i.e., cost and integration)?

Hybrid Production Imminent

Despite (and because of) the impressive engine advancements, production of hybrids is imminent as evidenced by the competitive positioning (i.e., alliances, acquisitions, investment and increased development) and the early market introductions by Toyota and Honda.

The first high volume 'hybrids' (though they may not be called that) will use ISAD technology for several reasons:

auto industry is nverging on a global 42v standard electrical system. ISAD hardware is necessary to provide 6-10 kW needed for high

power auxiliaries, including electromechanical valves, electric power steering, electric air conditioning, etc. An alternator with a belt drive cannot handle the projected power requirements. Moreover, the no-idling law being discussed in Europe may necessitate the ability to turn off the engine while operating accessories.

•ISAD technology is expected to cost no more than the replaced parts, including the starter, alternator and flywheel (hence the phrase “no-cost transition”). Of course, additional components (e.g., batteries/capacitors) will be necessary to get all the benefits of a parallel hybrid.

•Depending on the configuration and control strategy, it can improve fuel economy and emissions 15-30%.

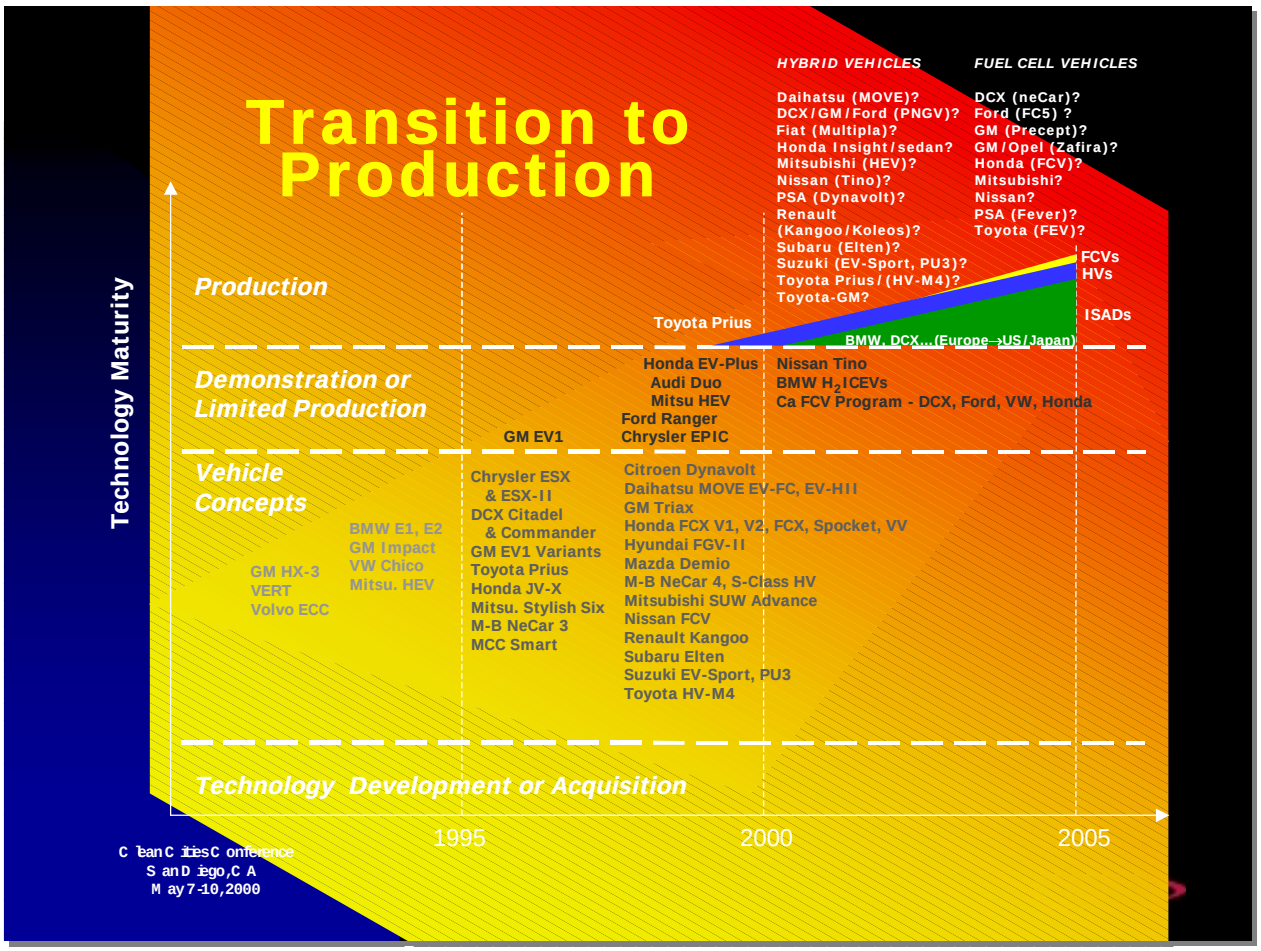
•Low-risk, immediate benefits – integrate batteries or capacitors as they mature.

Product Mix in Transition

What hybrid products will reach the market in the near-term? Momentum toward production has been building for some time and the turning point was the Toyota Prius. Consequently, many manufacturers will introduce hybrids in the marketplace in the next few years.

All the major manufacturers have displayed concepts in past years and months - shown in the lists on the following figure.

The ‘ISADs’, with 42v electric accessories and various levels of ‘hybridization’, are expected to become the baseline over the next five years. Siemens is apparently leading the way with BMW and/or DCX next year, followed closely by widespread application by automakers in the US and/or Japan.



Sales of hybrid vehicles with substantial electric range ("HVs" on the figure) will be slow initially due to:

•Immature and/or high cost electric drive components (primarily energy storage).

•Conventional vehicles with ISAD units are low-risk for the automakers.

•Foreseen regulatory requirements can be met with advanced IC engines combined with ISAD units – consider the potential of the SULEV Accord with the additional benefits of an ISAD unit.

The small impact of fuel cell vehicles during this period is based on the substantial cost and technical challenges that must be resolved prior to volume production and sales. Despite the apparent momentum of technological advancements described in press releases and reflected recently in stock prices, fuel cells are not expected to be available in production quantities until sometime beyond the immediate period of interest.

Global Influence Factors

Economic factors affecting the production and sale of hybrid vehicles are global in nature since their success in the US depends on technology transfer through the new automotive alliances around the world.

A recent study in support of the IEA Hybrid Vehicle Annex VII, whose objective was to identify global influence factors on the production and sale of hybrid vehicles, surfaced several important factors.

•Vehicle production costs appear similar in Europe and the US - implying that a hybrid propulsion system must cost $2,500 or less (in a $20,000 car) to compete.

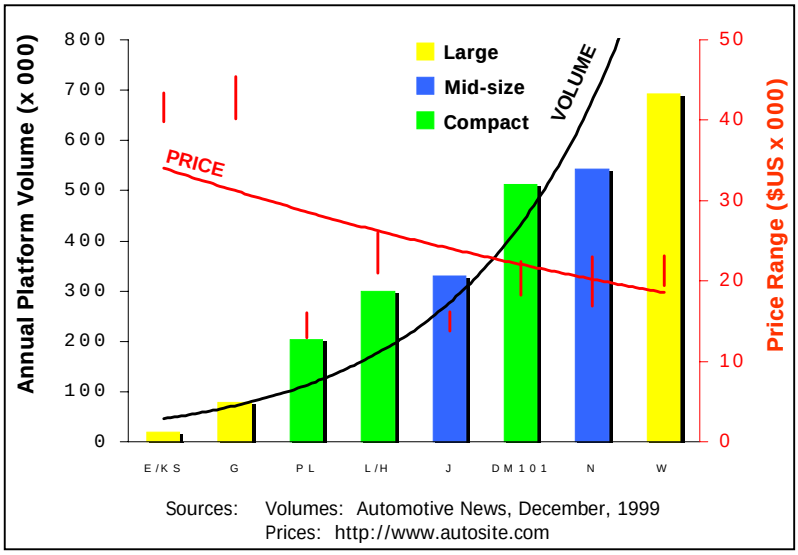
•Consumers' willingness to pay a premium for fuel economy and emissions improvements is limited. Studies by NREL found that consumers in the US might pay 10 to 15% more for a 50% increase in fuel economy. In fact, combining the results of several surveys, they found that fuel economy has not been an important consideration since the mid-1980s. The EU and Asia IEA members did not supply consumer preference data. However, the EU members' comments implied that consumers there are similar to elsewhere in the world - styling, utility, and other factors influence purchase decisions as much as fuel economy.

•Government policy has a major impact on prices and profitability - through mandates and regulations in the US and taxes in the EU.

•Incentives are widely used to influence the production or sale of electric and hybrid vehicles, however IEA members felt that these would not last when environmental vehicles reach substantial production levels.

Price Limits

Perhaps the most limiting factor regarding the sale of hybrid vehicles is the price of the competition. Most cars sell for $20,000 to $25,000, shown in the chart of price versus volume.



Sources: Volumes: Automotive News, December, 1999
Prices: http://www.autosite.com

Despite the introduction of the Prius and Insight at prices below $20,000, hybrid vehicles are estimated to cost $2,000 to $10,000 more than a comparable conventional vehicle. The typical profit margin of a $20,000 car cannot absorb the potential cost increase.

Subsidies for New Technology

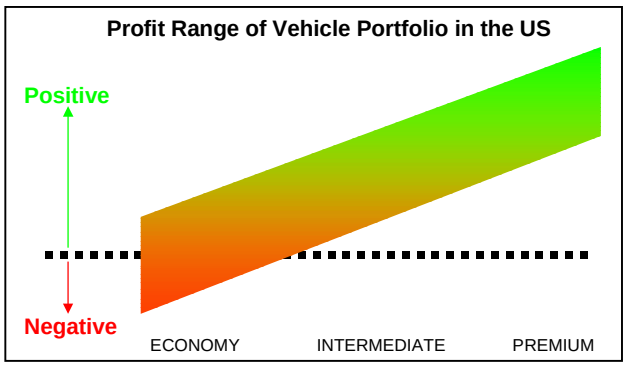
New technology requires initial support to compete at low production volumes. Manufacturers typically subsidize through introductory prices or the customer pays a premium (to get the latest model). If a product contributes to government objectives as well (e.g., lower fuel consumption and emissions), they may choose to participate. The Toyota and Honda hybrid vehicles are examples of combined commitments of the companies and their government.

Government involvement in hybrid vehicles cannot be relied upon on a long-term basis because low volume production does not substantially benefit the public and supporting high volume production cannot be justified.

Hybrids Could Ease CAFE Pressure

Why would manufacturers subsidize new, but unprofitable products? Usually the reason is to capture market share in a market with growth potential. In the US, where the vehicle mix is influenced by CAFE, there are other reasons.

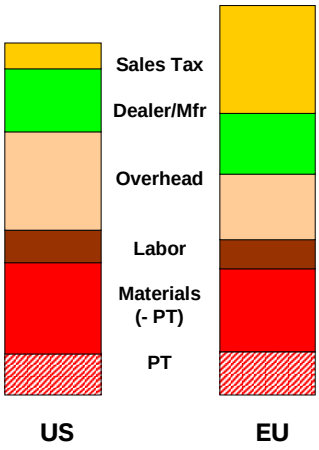
The chart shows the general range of profitability for US manufacturers versus vehicle type. Consumer preferences for large cars and trucks have caused manufacturers to influence the market mix by selling high-fuel economy vehicles at little or no profit to balance the sale of intermediate and premium cars that get lower fuel economy.



The demand for Sport Utility Vehicles has exacerbated the problem for US manufacturers and SUVs have surfaced as obvious candidates for hybridization - due to their low fuel economy, high market share and high profit margins.

Tax Relief in the EU?

Though the vehicle production cost structures are similar in Europe and the US, taxes differ substantially. Sales taxes range from 16-18% VAT to 218% of the price. This is an obvious opportunity for the EU to influence the market with tax breaks for hybrid vehicles. Several countries offer tax relief for environmental vehicles now, but sales are so small it an inexpensive gesture.



Mainstream Market Potential if…

Hybrid vehicles have unlimited market potential if they are competitive in cost, reliability and durability. Hybrids must use mainstream development and production processes to get sufficient quality. Moreover, if hybrid vehicles in production yield substantial fuel economy and emissions improvements (>50%), they should be credited accordingly. Total energy consumption and air quality will benefit greater from selling millions of hybrids with efficient, clean engines rather than limited sales of ZEVs.