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New Vehicle Technologies: How Soon Can They Make a Difference?

MIT transportation experts have some pragmatic projections that send a clear warning: we must not be overly optimistic about how quickly changes in vehicle technology can reduce America's staggering consumption of petroleum for transportation.

According to their calculations, it will be some two decades before even moderately improved technology vehicles will be on the roads in sufficient numbers to make a difference. And the much-touted hydrogen fuel cell hybrid vehicle is unlikely to be a common on-road sight for more than 50 years. Given such long lead times, it is imperative that we begin to pursue those changes immediately and aggressively.

For the past year, Professor John B. Heywood and graduate student Anup P. Bandivadekar have been examining how various government policies may affect long-term US petroleum use and emissions (see *energy & environment,* January–June 2004). Among those policies are regulations that encourage development of improved and new technologies for vehicles and fuels.

According to a comprehensive life-cycle assessment by Dr. Malcolm A. Weiss, Professor Heywood, and their colleagues, these improved and new vehicle and fuel technologies promise to be far more energy efficient than today's vehicles are (see references 2 and 3 in the References section). But these technologies will not actually affect America's energy consumption until they come into widespread use, and predicting how long that change will take is a challenge.

Vehicle technologies have changed in the past. For example, fuel-injection systems replaced carburetors, and engine cylinders began having four valves instead of two—relatively minor changes that took about 15 years to occur. The expansion of diesels from 15% to roughly 50% of the new cars sold in Europe has taken about 20 years.

"But for a new technology like the hybrid, there's no prior example case study that says it'll take 15 years or 20 years," said Professor Heywood. "We haven't made this large a change in the last eighty-odd years. You have to go back to the 1920s for there to be competition between significantly different types of propulsion systems."

So how can one estimate the time needed for a technology to go from a not-ready-for-market concept to a large enough fraction of

Time Scales for New Vehicle Technologies to Affect US Transportation Energy Use

	Vehicle Technology			
Implementation Phase	Gasoline Direct-Injection Spark-Ignition Boosted Downsized Engine	High Speed Direct-Injection Diesel with Particulate Trap, NO_X Catalyst	Gasoline Spark-Ignition Engine/ Battery-Motor Hybrid	Fuel Cell Hybrid Vehicle, Onboard Hydrogen Storage
Market competitive vehicle	~ 5 years	~ 5 years	~ 5 years	~ 15 years
Penetration across new vehicle production	~ 10 years	~ 15 years	~ 20 years	~ 25 years
Major fleet penetration	~ 10 years	~ 10–15 years	~ 10–15 years	~ 20 years
Total time required	~ 20 years	~ 30 years	~ 35 years	~ 55 years

This table shows MIT estimates of how long it will take for four new vehicle technologies to be on the road in sufficient numbers to affect total US energy consumption for transportation. In the first phase, the technology must become market competitive in performance, convenience, and cost. In the second, it must become more than 35% of all the new vehicles manufactured. In the third, it must become responsible for more than 35% of total US miles driven. The total times (even allowing for overlap in the phases) demonstrate that new vehicle technology is far from a "quick fix" for America's enormous appetite for transportation energy.

the on-the-road fleet to make a difference? As a framework for tackling the problem, Professor Heywood and Mr. Bandivadekar divided the market-penetration process into three phases.

First, the technology must be developed to the point where it is market competitive. Financial incentives from government may help; but in the end the cost, performance, and convenience must be close enough to standard technology that people will want to buy the new vehicle in significant numbers.

Next, the new technology must grow from a modest fraction to a significant fraction of new vehicle production. To achieve that expansion, a manufacturer must use the new technology in numerous vehicle classes, say, compact cars and SUVs and pickup trucks. Each application will require new components (bigger batteries and motors, for example), so the company will need to build new production facilities. Even more time-consuming is the task of developing good designs for the different sizes and versions of the new technology.

Finally, the new technology must become a significant fraction of the on-the-road fleet and—most important—of total miles driven in the United States. The length of time required depends both on how many of the new vehicles are being manufactured (the previous phase) and on the typical lifetime of vehicles that are already in circulation (a determinant of the potential market for new purchases).

Before assessing specific technologies, the researchers had to define what "a significant fraction" meant in phases two and three. Professor Heywood stressed the importance of this definition. "We're trying to estimate 'time to impact,'" he said. "We're not concerned with getting a few new vehicles out there but rather with getting enough on the road to have an impact that in some ways you could discern or measure."

Guided by previous research experience, they estimated that a new vehicle technology would have a measurable impact on energy use when that technology is responsible for about 35% of the total US miles driven. To permit that level of market penetration, in phase 2 the new technology must be in 35% of the new vehicles produced.

The table on page 1 shows the researchers' assessment of four illustrative vehicle technologies: an improved gasoline spark-ignition engine, a diesel engine with improved fuel efficiency and very low emissions, a gasoline spark-ignition-engine hybrid, and a hydrogen fuel cell hybrid (with hydrogen stored onboard the vehicle).

The researchers estimated that the time needed for the first phase is roughly the same for the first three vehicle types. Each is about one "development cycle"—roughly 5 years—away from becoming market competitive. The hydrogen fuel cell is almost completely new technology, so the time required for the first phase is considerably longer.

The estimates in the second phase show more variation. Moving from improved gasoline to cleaned-up diesel to gasoline hybrid to fuel cell hybrid, the times become longer because the technologies become increasingly different from those in use today. As a result, expanding production to additional model types becomes more difficult.

The third-phase estimates show less variation from technology to technology but also increase as the technology becomes less familiar and production buildup is slower. In all cases, the lifetime of vehicles already on the road was assumed to be 15 years, the current average.

Finally, the researchers added up the times required for each technology, then subtracted a bit to account for overlap between the phases. The totals tell a surprising story. The improved gasoline engine—a technology that would seem relatively easy to develop and implement—will take some 20 years to have impact. The diesel requires about 30 years, the hybrid about 35 years, and the hydrogen fuel cell 50 to 60 years.

"I think the value of our approach is that it helps us avoid the trap of being overly optimistic as to how quickly through changes in technology—even near-term technology—we can impact overall US vehicle fleet fuel consumption," said Professor Heywood. "The idea that hydrogen will save us in the near term from our energy appetite is just nuts. You have to go through these stages; and while you can say we'll get through each stage much faster, there's no evidence that we've ever done that before."

The researchers have presented their analysis to audiences at MIT, in the automotive industry, and elsewhere; and the response has been supportive. People commend the researchers' new three-phase framework for thinking about the market-penetration process. Industry personnel stress the value of stepping back from near-term production challenges and taking this broad, strategic view. And there have been few quibbles with the numbers. Indeed, the researchers' initial estimate for the hydrogen fuel cell to become market competitive was 10 to 15 years. But "just about everybody in the business said they'll never do it in 10 years," so the lower number was dropped.

"The point is not that the numbers are tightly accurate," Professor Heywood said. "The point is that these time scales are all long, and some are very long. It adds urgency to the fact that we should start trying to prompt these changes right away."

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References

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