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Advanced Power Technology Survey

A Report for the Advanced Power Technology Alliance

November 2002

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Center for Automotive Research
Altarum Institute

Prepared for the Michigan Economic Development Corporation

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A REPORT FOR THE

ADVANCED POWER TECHNOLOGY ALLIANCE

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FOREWORD

The Advanced Power Technology Alliance is a program sponsored by the Michigan Economic Development Corporation and the Herbert H. and Grace A. Dow Foundation. The goal of the Alliance is to encourage the development of advanced power technologies and position the State of Michigan as a leader in this rapidly evolving sector.

The Advanced Power Technology survey is based on the Delphi forecasting process and is highly dependent upon the quality of the small 'expert' panel. Great care was taken to identify experts in important areas of advanced technology. These experts were then asked to respond to a questionnaire pertaining to advanced power technologies. The survey had 25 carefully selected respondents and each question had a response count of approximately 18-22. The Panel includes academics, automotive manufacturers and suppliers, fuel cell developers, and energy representatives. While these numbers are low for a traditional survey, work done by the Rand Corporation for the U.S. Air Force in the late 1960s indicates that a small panel of experts with an interactive review of results can be a highly effective method of forecasting.

A key point to keep in mind is that the expert panel forecast presents a vision of the future. It obviously is not a precise statement of the future but, rather, what the industry thinks the future will likely be. In retrospect, some topics and issues will be more accurately predicted, others less so; but the data and comments presented in this survey will influence the decision makers of today.

The survey data is presented in tables using arithmetic means for questions using a one through five scale. When the question calls for a response in the form of a number estimate, results are presented in medians with interquartile ranges (IQR). That is, the point at which 25 percent of the answers are below the lower IQR and the point where 25 percent of the answers are above the upper IQR. The IQRs are useful to illustrate the relative consensus of the panel. Narrow IQRs indicate a strong consensus while a wider spread suggests a lack of agreement or relative uncertainty. Panelists' edited comments are included to give context and color to the numerical tables. These comments are particularly useful in understanding questions where there are large differences in opinion due to uncertainty or differing strategies.

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EXECUTIVE SUMMARY

COMMERCIAL VIABILITY OF LIGHT-DUTY VEHICLE ADVANCED POWERTRAIN TECHNOLOGIES

A critical driver for the acceptance of advanced powertrain technology is the cost competitiveness of the gasoline internal combustion engine (ICE). The panel certainly expects the ICE to continue to present a challenging target in the coming decade for alternative fuels and powertrains. They forecast technologies such as direct injection gasoline engines, electronic cylinder shutoff, variable valve lifting and continuously variable transmissions to be commercially viable by 2012. They also see critical technology developments for diesel engines. Direct injection diesels, NO_x absorbers and particulate traps are all forecast to be commercially viable by 2012. The ability to cost effectively increase the efficiency and reduce emissions of internal combustion engines may serve as a difficult barrier for advanced powertrain technologies.

The panelists rate cost as the most severe barrier facing hybrid electric vehicles (HEV). Interestingly, they view the technical challenges of hybridization as presenting a relatively minimal barrier. Although the HEV can deliver greater fuel efficiency and reduced emissions vis-à-vis the internal combustion powered vehicle, it will be at a prohibitive cost disadvantage. Given the concern over cost, it is not surprising that the panel expects the integrated motor assist—the least costly of the hybrid layouts—as slightly more likely to be commercially viable for light vehicles by 2012 than the parallel layout, and much more likely than the series layout. However, they rate the parallel hybrid layout as more likely to be commercially viable than the integrated motor assist or the series layout for city buses and urban delivery trucks. An alternative to electric hybrids—hydraulic launch assist—is rated as somewhat likely to reach commercial viability by 2012.

FUEL CELL ACCEPTANCE AND HYDROGEN INFRASTRUCTURE

While much effort has been put into the development of fuel cells for applications in light-duty vehicles, many substantial barriers remain. The panel views the cost of the fuel cell and consumers' willingness to accept this increased cost as the most substantial barriers. However, the panel also views the development of the hydrogen infrastructure to be an equally substantial barrier. It is apparent that both cost and infrastructure present a huge challenge to the implementation of fuel cells in light-duty vehicles. While industry may be able to meet the technical and manufacturing challenges of developing a commercially viable fuel cell, the infrastructure will need to be a cooperative effort of government, automotive and energy industry participants, as well as many other stakeholders. Many of the basic elements of a hydrogen infrastructure are still uncertain. Panelists view the commercial viability of fuel cells for light vehicle applications as not likely by 2007, but likely by 2020.

The panel views it as likely that fuel cell technology will be commercially viable first in distributed power applications. Although there are currently several instances of fuel cell technology being used for distributed power or industrial-sited applications, these are demonstration programs. The panel rates as slightly better than somewhat likely that fuel cells will be commercially viable for distributed power applications within five years. The panel also indicates that fuel cells for residential, bus and micro-power applications are likely to be commercially viable by 2020.

The panel indicates that proton exchange membrane (PEM) fuel cells and solid oxide fuel cells (SOFC) are appropriate for distributed power and industrial-sited applications. Not surprisingly, they also indicate that PEM fuel cells are the most appropriate for transportation.

PUBLIC POLICY ACTIONS

While much attention has been given to a technological solution to decrease energy usage and concomitant greenhouse emissions reduction, the panel indicates sharply increased gasoline taxes would be an effective, although not popular, way to quickly reduce oil consumption. The panel also rates sharply increased Corporate Average Fuel Economy (CAFE) standards and incentives for diesel engines and hybrid electric vehicles as effective means of increasing fuel economy and reducing greenhouse gases.

The panel indicates that cost will be a severe barrier to the development of advanced power technologies. Therefore, public policy could be an important tool in encouraging the adoption of these new technologies. According to the panel, government (local, state or federal) purchase of alternative powered vehicles is an effective method of creating a market. The panel also views government funding of stationary applications for distributed power and industrial-sited advanced power technologies as an effective means of encouraging the development of these new technologies.

FUEL AND POWERTRAIN ISSUES

The price of gasoline, combined with the relatively inexpensive cost of the ICE, has set a difficult cost barrier for alternative powertrain development. The panel appears to believe gasoline will continue to be a relatively inexpensive energy source. They forecast the price of regular gasoline, including taxes, to be $1.75 in constant dollars in 2012. The panel forecasts the constant dollar price of premium gasoline to be $2.05 in 2012. While it is difficult, even impossible, to predict the price of oil, the panel's forecast is important because, while they have some insight into the future price of oil, many also have direct input into resource allocation for new products and for technology research and development. An important part of this strategic planning is based on the expected price of oil. Therefore, the forecast price of oil, even if somewhat of a guess, is a critical factor in determining where future resources will be allocated.

Given the forecast for relatively inexpensive gasoline, it is not surprising that the panel forecasts a continued dominance of gasoline as the energy source for light-duty vehicles in the coming decade. However, they also forecast increased usage of diesel fuel (10 percent share) by 2012. Grid based electric (0.5 percent), hydrogen (1 percent) and natural gas (2 percent) are forecast to attain small inroads into the light vehicle energy mix.

The panel forecasts that hybrid electric vehicles will account for 7.5 percent of the light duty market by 2012. Fuel cells are forecast to account for 1 percent of the market by 2012. The panel expects diesel engines to account for approximately 15 percent of the internal combustion engines in 2012. Given the present opposition to diesel technology from many states, such a forecast suggests the panel believes diesel engine emissions technology will be commercially viable, or at least technologically feasible and mandated by regulation, by 2012. Even if there are technologies developed to reduce NO_x and particulate emissions from diesels, panelists indicate the engine will still have to overcome the negative image it gained in the early eighties. Many customers in the U.S. recall the noisy, rough and generally unacceptable diesel engines that were on the market two decades ago. Although diesel technology has advanced greatly over that time, that lasting image will present a barrier to many.

The panel forecasts lower diesel penetration for hybrid electric vehicles. The added cost of the diesel engine, vis-à-vis the gasoline engine, may be a deterrent of increased usage of the technology for hybrid applications.

I COMMERCIAL VIABILITY OF LIGHT-DUTY VEHICLE ADVANCED POWERTRAIN TECHNOLOGIES

APTA-1 Please rate the likelihood that the following advanced internal combustion powertrain technologies will be commercially viable (positive return on investment going forward) for light vehicle application by 2007 and 2012, where 1 = extremely likely, 3 = somewhat likely, and 5 = extremely unlikely.

SCALE	1	2	3	4	5
	EXTREMELY LIKELY	LIKELY	SOMEWHAT LIKELY	NOT LIKELY	EXTREMELY UNLIKELY

ADVANCED INTERNAL COMBUSTION POWERTRAIN TECHNOLOGIES	2007	2012
	MEAN RESPONSE	MEAN RESPONSE
DIRECT INJECTION ICE - DIESEL	2.3	1.4
VARIABLE VALVE LIFT TIMING	2.2	1.4
PARTICULATE TRAPS	2.2	1.5
CONTINUOUSLY VARIABLE TRANSMISSION	2.7	1.6
DIRECT INJECTION ICE - GASOLINE	2.6	1.7
NO_X ABSORBERS	2.6	1.7
ELECTRONIC CYLINDER SHUTOFF	2.6	1.8
ELECTRONIC VALVE ACTUATION (A.K.A. CAMLESS VALVE ACTUATION)	3.4	2.2
CATALYST PRE-HEATERS	2.9	2.5
HYDRAULIC LAUNCH ASSIST	3.6	2.8
HYDROGEN-POWERED INTERNAL COMBUSTION ENGINE	4.3	3.2

COMMENTS

- These assignments are for North America. For Europe and Asia, the introduction of combustion ignition direct injection (diesel) and GDI will pace North America's introduction of technologies.
- Electronic valve actuation probably requires 42 volt DC electrical systems. This is very unlikely to occur before 2007. Fully hydraulic camless technology is also a possibility and does not require 42 volt technology.
- Since some of these developments (such as No_x absorbents) are regulatory driven, the idea of commercial viability is not truly applicable.
- DI diesel: Assumes personal use vehicles at 15,000 miles/year and U.S. fuel prices at current trend. In Europe, this is already at "extremely likely." Hydrogen: Cost of infrastructure is borne by whom? CVT: Long-term durability issues will lead to a decline in "market value" of CVT investment.

STRATEGIC CONSIDERATIONS

The results suggest that the greatest hurdle to alternative technologies may be the rapid evolution of the internal combustion engine and its drivetrain. All of the listed technologies, with the exception of the hydrogen-powered internal combustion engine, are viewed as at least somewhat likely to be commercially viable in the coming decade. Each of the technologies offers the opportunity to reduce the internal combustion engine's footprint on the environment, making an already cost effective powertrain more environmentally acceptable. The comment regarding the regulatory nature of many of these technologies is important. Much of the development of emissions and fuel economy has been driven by regulation. However, some companies are making the introduction of the advanced clean internal combustion engine a competitive advantage.

Although direct injection (DI) diesels are already gaining market acceptance in Europe and Japan, its acceptance, or the acceptance of any diesel technology, in the U.S. is far less certain. Diesel engines offer significant fuel economy improvements and CO_2 reductions vis-à-vis gasoline engines. However, particulates and NO_x remain significant barriers for diesel penetration in the United States. Panelists indicate that particulate traps and NO_x absorbers may be a cost viable approach to addressing these challenges in the coming decade.

The gasoline direct injection engine has also seen initial application in other regions. Gasoline direct injection offers the potential for significant gains in fuel economy, some emissions reduction (although NO_x and hydrocarbons are problematic) and even increased horsepower output. Important work remains on the catalysts that are required for DI engines to meet U.S. regulation. Current catalysts are contaminated by the sulfur found in U.S. gasoline and, thus, cannot meet the technical requirements.

Variable valve timing is currently offered by several manufacturers and will likely be increasingly used. It could, therefore, be argued that this technology is already cost effective for some manufacturers in some segments. Continuously variable transmissions (CVT) are also offered by at least three manufacturers. The real challenge for the CVT may not be reaching manufacturing viability, but durability and torque.

The panel rates as only somewhat likely that hydraulic launch assist will be a commercially viable technology by 2012. While this technology may have some application for larger light duty trucks, the ability of this technology to be applied to heavier vehicles may prove especially effective for the urban delivery segment.

The panel also rates the cost viability of the hydrogen-powered internal combustion engine as only somewhat likely. Several manufacturers are working to develop hydrogen-powered ICE technology as either a first step toward the hydrogen infrastructure or as a potential alternative to fuel cells. While the technology is not likely to be as efficient as PEM fuel cells, it is possible that the hydrogen-powered ICE may be commercially viable far sooner than the fuel cell.

Computer-controlled engine management has made electronic cylinder shutoff a potentially viable strategy to increase fuel economy for larger vehicles. Electronic valve actuation also offers promise, but as the comment suggests, will likely require a switch to 42 volt electrical systems before it is feasible, whereas hydraulic camless technology presents a more viable opportunity with the current voltage system.

Finally, it is important to reiterate that several of these technologies will require significantly lower levels of sulfur in the fuel. Within the automotive community, many suggest that the oil industry has been slow to act on this issue. Without a coherent strategy to remove sulfur from the fuels, these technologies will not be able to deliver the hoped for benefits in emissions and fuel consumption reduction.

APTA-2 Please rate the severity of the following barriers to hybrid electric vehicle (HEV: internal combustion engine/electric) viability for light-duty vehicles, where 1 = a substantial barrier, 3 = somewhat of a barrier, and 5 = not a barrier at all.

SCALE	1	2	3	4	5
	A SUBSTANTIAL BARRIER	A BARRIER	SOMEWHAT OF A BARRIER	A SLIGHT BARRIER	NOT A BARRIER AT ALL

BARRIERS	MEAN RESPONSE
CONSUMER ACCEPTANCE	
COST	1.9
TECHNOLOGY ADOPTION	3.6
PERFORMANCE	3.7
ELECTRICAL HAZARDS	4.3
BATTERY PERFORMANCE	2.5
ULTRA CAPACITOR DEVELOPMENT	2.8
POWER ELECTRONIC DEVELOPMENT	3.5
CLEAN ICE TECHNOLOGY	3.6
ELECTRIC MOTOR DEVELOPMENT	3.8

COMMENTS

- Standardization of hybrid vehicle (HV) system voltage could be somewhat of a barrier unless the industry decides to standardize on the energy storage system modules (voltage, charge balance mechanisms, fault management, etc). At present, module voltage standards appear to be 12 volt, 8 volt for lead-acid (Pb-Acid) and 7.5 volt nickel metal hydride (NiMH).
- The cost is still a strong barrier to HEVs to help mass introduction.
- The key issues are cost (without OEM subsidies or artificial tax incentives) and any perceptible performance compromise.

OTHER

- Battery cost: 2
- Comfort: 2
- Engine stop/start in traffic: 2

STRATEGIC CONSIDERATIONS

The panel does not view most of the listed barriers as presenting a significant challenge. However, they do identify several barriers. Not surprisingly, cost is the most substantial barrier to increased penetration of light-duty hybrid vehicles. Given current gasoline prices, the price penalty for the added technology of a hybrid vehicle may be greater than the life cycle gasoline savings realized by the initial owner. While the cost of hybrid technology will likely be lowered through engineering cost reductions and scale economies, the cost of two drivetrains—one electric and one mechanical—will make it difficult to meet cost targets set by traditional ICE-powered vehicles. However, some panelists suggest that consumers are placing an increasingly higher value on environmental issues. Such a change in values could reduce the importance of cost as a barrier. Of course, incentives such as tax credits could significantly enhance consumer acceptance.

Technical barriers also exist. The panel views the development of acceptable battery performance as a technical challenge that may threaten the growth of hybrids. Much effort has been focused on battery development over the last decade, yet much work remains. The panel sees the development of an effective ultra capacitor as a barrier, yet the development of an effective ultra capacitor with its quick charge capability, could have a significant boost for hybrid technology.

APTA-3 Please rate the likelihood that the following hybrid electric vehicle layouts will be commercially viable (positive return on investment going forward) for the listed applications by 2007 and 2012, where 1 = extremely likely, 3 = somewhat likely, and 5 = extremely unlikely.

SCALE	1	2	3	4	5
	EXTREMELY LIKELY	LIKELY	SOMEWHAT LIKELY	NOT LIKELY	EXTREMELY UNLIKELY

HYBRID ELECTRIC VEHICLES	2007	2012
	MEAN RESPONSE	MEAN RESPONSE
LIGHT VEHICLES		
INTEGRATED MOTOR ASSIST	2.4	1.8
PARALLEL HYBRID LAYOUT	2.6	2.1
SERIES HYBRID LAYOUT	3.6	3.2
HIGHWAY COMMERCIAL VEHICLES		
INTEGRATED MOTOR ASSIST	3.5	3.1
PARALLEL HYBRID LAYOUT	3.4	2.8
SERIES HYBRID LAYOUT	3.8	3.5
CITY BUSES / URBAN DELIVERY		
INTEGRATED MOTOR ASSIST	3.1	2.6
PARALLEL HYBRID LAYOUT	2.7	2.1
SERIES HYBRID LAYOUT	3.3	2.9

COMMENTS

- Integrated motor assist is primarily an idle-stop measure and most easily introduced on light vehicles. It requires substantial supporting technology that diminishes its value equation. Parallel hybrid technology will become more viable as energy storage system cost and cycle life durability are improved. Series hybrid vehicles require very efficient components (locomotive architecture) or a very controllable engine (load tracking architecture).
- Commercial viability is highly dependent on government-based incentive programs (grants/tax credits).

STRATEGIC CONSIDERATIONS

The results indicate that panelists believe integrated motor assist (IMA) and parallel hybrid architectures will likely be commercially viable for light vehicles by 2012. There is currently little work being done with series hybrid architecture for light vehicles. IMAs offer shut down capability but also permits decreased engine displacement at equivalent vehicle performance, leading to increased fuel economy and reduced emissions. There is important work being done in both the in-line motor assists, such as the Honda Insight, and in the belt-driven starters under development at several companies.

The respondents are somewhat less positive regarding hybrid technology for highway commercial vehicles. They rate the commercial viability of IMAs and parallel architectures as slightly better than somewhat likely and the series hybrid as slightly less than somewhat likely. The series hybrid layout is viewed as less likely for application in the listed applications. It is interesting to note that the main competitor to long distance trucking, diesel electric locomotives, have used series hybrid layout for decades.

The driving patterns for city buses may be ideal for hybrid technology use. The frequent stops with idle shut-off and short runs followed by the opportunity for regenerative braking offer potential for significant emissions fuel consumption reductions. Although much has been made of the few fuel cell-powered buses in operation, less publicity has been given to the hybrid buses also on the road. Although these hybrid buses offer potential for significant environmental benefits, they have not necessarily caught the attention of the press and public. Vehicles such as the General Motors-Allison Transmission series hybrid bus may offer a 40 percent increase in fuel economy and a 70 percent reduction in emissions. Such technology may provide a much more cost efficient means of reducing emissions in the near term than fuel cells. The National Automotive Center (NAC) is also actively developing heavy-duty hybrid vehicle technology that may have direct application for urban delivery (e.g., refuse collection) vehicles. It is also important to note that hydraulic launch assist (HLA) could offer some competition to hybrid electric application in the urban delivery market. Some early indications are that HLAs may offer a cost competitive alternative to the electric motors and sophisticated power electronics required for hybrids.

II FUEL CELL ACCEPTANCE AND HYDROGEN INFRASTRUCTURE

APTA-4 Please rate the severity of the following barriers to light duty fuel cell vehicle market penetration, where 1 = a substantial barrier, 3 = somewhat of a barrier, and 5 = not a barrier at all.

SCALE	1	2	3	4	5
	A SUBSTANTIAL BARRIER	A MODERATE BARRIER	SOMEWHAT OF A BARRIER	A SLIGHT BARRIER	NOT A BARRIER AT ALL

BARRIERS	MEAN RESPONSE
CONSUMER ACCEPTANCE	
COST	1.1
RELIABILITY / DURABILITY	2.1
PERFORMANCE	2.7
TECHNOLOGY ADOPTION	3.0
FUEL CELL TECHNOLOGY	
COST OF FUEL CELL STACK	1.1
COLD START / PERFORMANCE OF FUEL CELL	2.0
FUEL CELL MEMBRANE DEVELOPMENT	2.4
TRANSIENT POWER DELIVERY	2.8
WEIGHT OF STACK AND COMPONENTS	2.8
BALANCE OF FUEL CELL PLANT TECHNOLOGY	
ON-VEHICLE HYDROGEN STORAGE	1.8
REFORMER TECHNOLOGY	1.9
BATTERY PERFORMANCE	2.7
AIR COMPRESSORS / BLOWERS	3.2
SEALING SYSTEMS	3.3
HEAT EXCHANGERS	3.5
POWER ELECTRONICS DEVELOPMENT	3.5
SENSORS AND CONTROL VALVES	3.7
ELECTRIC MOTOR DEVELOPMENT	3.9
HYDROGEN DELIVERY INFRASTRUCTURE	1.5

COMMENTS

- Fuel cells still have complexity and durability issues. Also, customers are apprehensive of hybrids due to lack of education. For fuel cells, the problem is more acute.
- Hydrogen is lighter than air and has no odor or color. A two car attached garage is a substantial barrier: any leak that is undetected could pose an explosive risk when the garage door opener is activated.

- Balance of fuel cell plant technology, reformer technology: None of the proposed onboard reformer technologies appear to make economic sense versus the same fuel and further development of ICE.

STRATEGIC CONSIDERATIONS

The cost of the fuel cell and the development and cost of the hydrogen infrastructure to support the fuel cell are viewed by far as the most critical barriers to fuel cell applications in light vehicles. Much has been made of the severe cost challenges facing the fuel cell, yet there are other significant concerns. Many of the basic elements of a hydrogen infrastructure are still uncertain. The delivery and onboard storage of hydrogen are seen as strong barriers. There are various hydrogen creation and delivery options but none have proven to be more viable than the other. For example, it is illustrative that the panel rates both onboard hydrogen storage and reformer technology as slightly more than a moderate barrier. Industry and government face a difficult dilemma—there is the need to develop standards to expedite development, yet the adoption of standards, if adopted before the competing technologies are fully researched, could lead to a less than optimal solution.

Reliability, durability and fuel cell membrane development are rated as moderate barriers. While most agree that the PEM is the most likely candidate for vehicle application, reliability and durability of the PEM fuel cell remain significant concerns. Fuel cells have yet to approach the required durability targets. Although much effort has been given to the development and refinement of membranes, there is still significant work to be done. The rate of membrane development is a factor that must be closely watched. It is conceivable that the membrane material that finally delivers an acceptable cost/performance/durability equation has yet to be invented.

The results indicate that the panel believes the balance of plant for the fuel cell (air, heat and fluid management) will not present a substantial barrier to fuel cell application. Much of the expertise required for the balance of plant is merely advancements of systems or technologies familiar to the automotive industry. Seals, pumps, radiators and other such components will have to be greatly improved but may largely resemble their ICE predecessors. Another interesting alternative is that due to cost concerns, the ability to eliminate any balance of plant components or systems will increase the cost competitiveness of the overall system. It is possible that the cost competitive fuel cell balance of plant may be drastically different from current designs.

APTA-5 Please rate the likelihood that the following advanced power technologies will be commercially viable (positive return on investment going forward) for the listed applications by 2007, 2012 and 2020, where 1 = extremely likely, 3 = somewhat likely, and 5 = extremely unlikely.

SCALE	1	2	3	4	5
	EXTREMELY LIKELY	LIKELY	SOMEWHAT LIKELY	NOT LIKELY	EXTREMELY UNLIKELY

ADVANCED POWER TECHNOLOGIES	MEAN RESPONSE		
	2007	2012	2020
FUEL CELL FOR DISTRIBUTED POWER APPLICATIONS	2.8	1.7	1.3
FUEL CELL FOR MICRO POWER APPLICATIONS	3.2	2.2	1.6
FUEL CELL FOR INDUSTRIAL FACILITY APPLICATIONS	3.2	2.1	1.7
FUEL CELL FOR CITY BUSES AND URBAN DELIVERY VEHICLES	3.6	2.6	1.8
FUEL CELL FOR RESIDENTIAL APPLICATIONS	3.4	2.6	1.9
FUEL CELL FOR LIGHT DUTY VEHICLE APPLICATIONS	4.1	3.2	2.2
GASOLINE INTERNAL COMBUSTION ENGINE WITH FUEL CELL AUXILIARY POWER UNIT	3.5	2.7	2.2
FUEL CELL FOR COMMERCIAL HIGHWAY VEHICLES	4.5	3.4	2.4
METHANOL REFORMER FOR FUEL CELLS	4.0	3.4	3.1
STIRLING ENGINE FOR STATIONARY APPLICATIONS	3.7	3.2	3.1
GASOLINE REFORMER FOR FUEL CELLS	4.0	3.6	3.3
STIRLING ENGINE FOR (MOBILE) TRANSPORTATION APPLICATIONS	4.5	4.1	3.8

COMMENTS

- Natural gas or propane fired fuel cells for stationary and residential power in a few kilowatts will be very attractive as power grid capacity becomes even more overloaded.
- Methanol reformer for fuel cells: When the cost of growing biomass needed is in the equation, this will probably never make sense.

OTHER

- Natural gas reformer/fuel cell for residential use: 2007-4, 2012-3, 2020-2

STRATEGIC CONSIDERATIONS

The results indicate that fuel cells are likely to first achieve commercial viability for application in distributed power, industrial facilities and micro power. Most current business cases for fuel cells are built upon the assumption that fuel cells for stationary applications will be viable long before the technology is ready for transportation uses. Rising interest in microgrids and distributed power generation further increases the potential for stationary applications in the next several years.

Military applications may also offer early opportunity for fuel cell application. The high cost of transporting diesel fuel to the battlefield and the rapidly increasing need for electricity on the battlefield (a result of the technology required by the modern military) have increased the military's interest in alternative power technologies. Given the military's ability to pay premium prices, they may play a role as an early adopter of fuel cells.

The panel rates as not likely the commercial viability of fuel cells for light vehicle applications by 2007. While there has been much activity—some real and some hype—surrounding fuel cells for transportation purposes, there is still much work to be done before fuel cells are a viable technology. The panelists indicate it is possible that a commercially viable fuel cell for automotive applications may not be available for 20 or more years.

The Stirling engine has been an alternative candidate for automotive applications for many years. Today, there is limited research underway but significant progress appears to be occurring. On any research where there are relatively few companies involved, it is difficult to forecast trends since key data may not be widely known across the technical community. The panel has far lower expectations for Stirling engines than they do for fuel cells. However, as with many technologies, the Stirling offers interesting potential and developments must be closely monitored.

APTA-6 Please rate the appropriateness of each of the following types of fuel cells for the listed mobile and stationary applications, where 1 = extremely appropriate, 3 = somewhat appropriate, and 5 = not at all appropriate.

SCALE	1	2	3	4	5
	EXTREMELY APPROPRIATE	APPROPRIATE	SOMEWHAT APPROPRIATE	NOT VERY APPROPRIATE	NOT AT ALL APPROPRIATE

FUEL CELL TYPES	MEAN RESPONSE
DISTRIBUTED POWER APPLICATIONS	
ALKALINE (OR BASIC)	2.9
MOLTEN CARBONATE	3.1
PHOSPHORIC ACID	3.1
PROTON EXCHANGE MEMBRANE	2.1
SOLID OXIDE	2.2
INDUSTRIAL CUSTOMER-SITED APPLICATIONS	
ALKALINE (OR BASIC)	3.1
MOLTEN CARBONATE	2.6
PHOSPHORIC ACID	2.7
PROTON EXCHANGE MEMBRANE	2.0
SOLID OXIDE	2.1
RESIDENTIAL CUSTOMER-SITED APPLICATIONS	
ALKALINE (OR BASIC)	3.7
MOLTEN CARBONATE	4.4
PHOSPHORIC ACID	4.2
PROTON EXCHANGE MEMBRANE	1.8
SOLID OXIDE	3.1
MOBILE (TRANSPORTATION) APPLICATIONS	
ALKALINE (OR BASIC)	4.0
MOLTEN CARBONATE	4.4
PHOSPHORIC ACID	4.3
PROTON EXCHANGE MEMBRANE	1.8
SOLID OXIDE	3.1
MICRO-POWER APPLICATIONS (I.E., LAPTOP COMPUTERS)	
ALKALINE (OR BASIC)	4.4
MOLTEN CARBONATE	4.6
PHOSPHORIC ACID	4.3
PROTON EXCHANGE MEMBRANE	1.9
SOLID OXIDE	3.9

COMMENTS

- I am not sure what your category “distributed power” refers to, as we would categorize all of the other categories as such. If this is to mean “utility grid” based (i.e., at substations), it could be relabeled as “utility power.” In addition, are you combining truly industrial applications with commercial (i.e., manufacturing vs. offices), etc.?

OTHER

- Micro power applications: direct methanol fuel cell / direct ethanol fuel cell: 2
- Direct methanol: 1

STRATEGIC CONSIDERATIONS

The panelists rate PEM fuel cells as the most viable technology for residential, transportation and micro-power applications. PEM fuel cells are being considered for residential and smaller wattage stationary applications (up to approximately 10 megawatt), yet there appear to be many challenges. Fuel cells are most efficient when operated in steady state (little or no transient power requirement). In fact, the transient power cycles of the residential—with peak energy requirements for air conditioning startup of up to 10 times the normal load needs—suggest that the residential fuel cell will need to have either some form of ultra capacitor, battery or grid backup to operate at an efficient load level. Current research for transportation applications has focused almost entirely on PEM technology. Thus, the panelists' rating of PEM fuel cells as the most viable for transportation is not surprising.

Solid oxide fuel cells are rated as appropriate for distributed power and industrial-cited applications. In fact, solid oxide fuel cells are likely better suited to the higher power requirements of distributed power and industrial applications than is the PEM. There also appears to be significant support for several of the other types of fuel cells. These technologies should be closely monitored.

Micro-power applications present many interesting possibilities. It is important to note that although the panelists indicate PEM fuel cells are most viable for micro applications, and much effort is being put into the technology, there is also some important activity in solid oxide fuel cells for micro power. While much work is underway for fuel cells to power laptops, cell phones and other small electronics, it is the military that might provide the initial opportunity for increased volume. The modern soldier's battlefield energy requirements are at unprecedented levels. Micro-power fuel cells may offer the potential to meet these increasing power requirements. Given the military's ability to pay a price premium for some technologies, the military market may be a critical step in the goal of reaching scale economies.

APTA-7 Please rate the severity of the following barriers in the development of a hydrogen infrastructure, where 1 = very severe, 3 = somewhat severe, and 5 = not at all severe.

SCALE	1	3	5
	VERY SEVERE	SOMEWHAT SEVERE	NOT AT ALL SEVERE

DEVELOPMENT OF HYDROGEN INFRASTRUCTURE	
BARRIERS	MEAN RESPONSE
COST OF HYDROGEN INFRASTRUCTURE	1.4
CONVERSION COST FOR HYDROGEN STATIONS	1.9
ENERGY COMPANY INVESTMENT	1.9
CONCERN OVER HYDROGEN SAFETY	2.3
ON-VEHICLE HYDROGEN STORAGE	2.3
GOVERNMENT INVESTMENT	2.6
HYDROGEN TRANSPORTATION	2.6
CODES / STANDARDS	2.7
ENERGY LOSSES IN HYDROGEN PRODUCTION	3.0
HYDROGEN STORAGE AT REFUELING STATION	3.0
GOVERNMENT / INDUSTRY RELATIONSHIP	3.1
HYDROGEN CREATION	3.5

COMMENTS

- Hydrogen transportation: Onsite production by stationary reformers or electrolyzers eliminates H_2 transportation.

OTHER

- Lack of political leadership: 2

STRATEGIC CONSIDERATIONS

The hydrogen economy has been discussed for decades, yet in many ways, the idea seems to still be a distant dream. Panelists rate all of the listed barriers as at least somewhat severe. Of all the listed barriers, cost—both the cost of the conversion or development of hydrogen stations and the cost of the rest of the required infrastructure—stands out as the most daunting. There are many estimates of the cost of converting the transportation fueling infrastructure to hydrogen. Although these estimates vary, it is generally agreed that a shift to a hydrogen economy must be funded, at least in part, by the federal government. Thus, it is noteworthy that the panel rates government investment as an important barrier.

The panel also indicates that energy company investment will be an important barrier. Obviously the oil industry and the automotive industry have considerable investment in the current refining and distribution infrastructure and traditional engine and transmission facilities respectively. It is possible that investment requirements will serve as a political and economic barrier to the development of a hydrogen infrastructure.

Another area of critical importance is the development of a hydrogen delivery infrastructure. Obviously, the delivery infrastructure will, to a great extent, be defined by the choices made for hydrogen creation. The infrastructure will vary significantly depending on whether the hydrogen is created at a central processing plant, onsite at the hydrogen refueling station, or some variation of those alternatives. Initial work by researchers at Argonne National Laboratory and others has begun the difficult process of developing delivery infrastructure models.

The panelists indicate that the perceived safety of hydrogen will also be a severe barrier. Consumers have had 100 years to grow accustomed to the handling of a toxic and flammable fuel—gasoline. Yet to many consumers, hydrogen suffers from the ‘Hindenberg syndrome’—that of great flammability. If consumers are to accept hydrogen as a power source, it is essential for codes and standards to be quickly developed. Consumers will need to see successful (i.e., safe) application of hydrogen-fueled power systems.

APTA-8 Please rate the relative energy consumption of generation and cost of generation for the following methods for creating hydrogen vis-à-vis gasoline refining, where 1 = significantly higher than gasoline refining, 3 = slightly higher than gasoline refining, and 5 = somewhat lower than gasoline refining.

SCALE	1	2	3	4	5
	SIGNIFICANTLY HIGHER (GREATER THAN 50%)	SOMEWHAT HIGHER (25-50%)	SLIGHTLY HIGHER (5-25 %)	EQUAL TO GASOLINE REFINEMENT (+/-5%)	SOMEWHAT LOWER (5-25%)

HYDROGEN CREATION PROCESSES	ENERGY CONSUMPTION IN CONVERSION	RELATIVE COST OF CONVERSION
	MEAN RESPONSE	MEAN RESPONSE
BIOMASS CONVERSION	2.6	2.3
COAL GASTIFICATION	2.0	2.0
ELECTROLYSIS OF WATER	1.6	1.4
PARTIAL OXIDATION OF HEAVY PETROLEUM OILS	2.7	2.6
PHOTOELECTROCHEMICAL	2.0	1.7
STEAM REFORMING OF NATURAL GAS	3.1	2.7

COMMENTS

- No comments.

STRATEGIC CONSIDERATIONS

There are many alternatives for creating hydrogen. It is possible that if the hydrogen economy does come to fruition, the hydrogen will be created using different methods depending on local resources. In many ways, it is not fair to have asked the panelists this question. Most of these technologies are in their developmental stages and significant improvement is likely and necessary. Certainly even the most advanced technologies have not met the scalability challenges that would be faced if widespread production of hydrogen was necessary. Nor is this a complete list of possible technologies. Wind power may play a role in the conversion process, as might nuclear technologies.

We ask that the reader treat this as the opinion of an informed panel and continue to monitor the listed technologies and others. The choices made as technology moves forward will have many implications. It is essential that the decision process be based on a systems approach and include a thorough understanding of the complete energy equation for the different alternatives.

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III PUBLIC POLICY ACTIONS

APTA-9 Please rate the effectiveness of the following federal strategies for encouraging the reduction in oil consumption and greenhouse emissions in the next five years, where 1 = extremely effective, 3 = somewhat effective, and 5 = not at all effective.

SCALE	1	3	5
	EXTREMELY EFFECTIVE	SOMEWHAT EFFECTIVE	NOT AT ALL EFFECTIVE

EFFECTIVENESS FOR REDUCING OIL CONSUMPTION AND GREENHOUSE EMISSIONS	
STRATEGIES	MEAN RESPONSE
SHARPLY INCREASED GASOLINE TAXES	2.2
SHARPLY INCREASED CAFE	2.5
INCENTIVES FOR HYBRID ELECTRIC VEHICLES (CUSTOMER OR MANUFACTURER)	2.5
INCENTIVES FOR APPLICATION OF DIESEL ENGINES (CUSTOMER OR MANUFACTURER)	2.8

COMMENTS

- It is obvious that federal strategies that make using oil prohibitively expensive will "encourage" the use of alternatives.
- Very little can be accomplished in a five-year period because of the huge number of vehicles already in use and regulatory lead-time needed by auto manufacturers and suppliers. Speed limits or gasoline taxes are the only thing that could be changed in a hurry, given the political will.
- Gasoline taxes and diesel incentives (consistent with real economics of diesels) are proven to work in Europe. The U.S. does not have the political will to follow Europe's lead. The U.S.-style incentives distort reality.

OTHER

- 55 mpg speed limit: 4
- Incentives for fuel cell vehicles: 2

STRATEGIC CONSIDERATIONS

While much attention has been given to the potential of fuel cells to greatly reduce petroleum consumption and greenhouse gas emissions (CO_2), most agree that widespread application of the technology is at least a decade off. Nearer term solutions should also be an important part of any energy (and national security) strategy. This nation faces a great challenge if these goals are to be given higher priority. Panelists rate all listed actions as somewhat effective, but differentiate little among the alternatives. Certainly the most immediately effective alternative—and possibly least palatable to the consumer—is a significant increase in gasoline taxes. Such an action could reduce overall miles traveled and rapidly shift the buying preferences of consumers away from larger inefficient vehicles towards smaller ones, or at least more fuel efficient ones. Yet there appears to be little political support for such an action and even less support from consumers.

Corporate Average Fuel Economy (CAFE) standards have proven to be less than effective and also appear to have little support from the consumer. However, CAFE has been a politically attractive method of imposing consumption constraints on the vehicle manufacturers. One serious problem with CAFE is that it creates a disconnect between automotive manufacturers and consumers. There is little incentive for consumers to purchase more fuel-efficient vehicles if they see few economic consequences.

Incentives for technology alternatives offer the opportunity to increase the number of fuel-efficient vehicles on the road. Incentives such as income tax credits and sales tax relief have been in place at the state and federal level but they present a substantial cost to the government and, in turn, to its citizens.

APTA-10 Please rate the effectiveness of the following public policy actions for encouraging the development and commercialization of advanced powertrain vehicles, where 1 = extremely effective, 3 = somewhat effective, and 5 = not at all effective.

SCALE	1	3	5
	EXTREMELY EFFECTIVE	SOMEWHAT EFFECTIVE	NOT AT ALL EFFECTIVE

PUBLIC POLICY ACTIONS	
LIST OF INCENTIVES	MEAN RESPONSE
MOBILE APPLICATIONS	
LIGHT VEHICLES	
GOVERNMENT (LOCAL, STATE OR FEDERAL) PURCHASE OF VEHICLES FOR FLEET USE	2.3
TAX CREDITS FOR VEHICLE PURCHASER	2.6
MASS TRANSIT (I.E., CITY BUSES)	
GOVERNMENT (LOCAL, STATE OR FEDERAL) PURCHASE OF VEHICLES	2.2
MORE RESTRICTIVE GOVERNMENT (LOCAL, STATE OR FEDERAL) EMISSIONS AND PERFORMANCE REQUIREMENTS FOR VEHICLES	2.3
HIGHWAY COMMERCIAL VEHICLE	
GOVERNMENT (LOCAL, STATE OR FEDERAL) PURCHASE OF VEHICLES	2.7
MORE RESTRICTIVE GOVERNMENT (LOCAL, STATE OR FEDERAL) EMISSIONS AND PERFORMANCE REQUIREMENTS FOR VEHICLES	2.4
TAX CREDITS FOR VEHICLE PURCHASER	2.5

COMMENTS

- Incentives are good to get policy adopted but customers need to see concrete examples first. Fleet usage is the best first step in adoption of new technology.
- Tax credits are a "dishonest," politically expedient approach. They reward certain technological choices, not actually achieving lower fuel consumption. Tax credits for the purchase of a 6,000 lb. hybrid electric vehicle would be insane when a 3000 lb. sedan with traditional IC power is more economical and cheaper to build.

OTHER

- Transit pass subsidy or other economic incentives: 2

STRATEGIC CONSIDERATIONS

Incentives will be essential if advanced power technologies are to gain commercial viability. These technologies present the opportunity for social benefit but at a cost to the user. Each of the listed policies is rated as at least somewhat effective. Local, state and federal governments are positioned to play a strong role creating early demand for advanced powertrain vehicles. Through purchase programs, government and even corporate fleets offer opportunity for manufacturers to gain volume production and introduce their vehicles into a controlled environment.

The comment regarding the value of tax credits for larger hybrid vehicles vis-à-vis smaller more fuel-efficient traditional internal combustion engine vehicles is interesting. While it is irrefutable that a policy to offer tax incentives for the purchase of a larger less fuel-efficient vehicle does raise an interesting policy question, it also may fail to take into account consumer preferences. For whatever reasons, many U.S. consumers have chosen to drive larger truck-like vehicles. Given this preference, it is questionable whether many consumers would be interested in driving a smaller sedan—even given a significant tax incentive. Instead, given the generally accepted premise that consumer choice is desirable, it may make more sense to concentrate on increasing the efficiency of larger vehicles, via tax credits for larger vehicles, with alternative powertrains. However, it is possible that environmental or national security issues will soon lead this country to assess the value placed on consumer choice compared to the implications of those choices.

APTA-11 Please rate the effectiveness of the following public policy actions for encouraging the development and commercialization of advanced power technologies, where 1 = extremely effective, 3 = somewhat effective, and 5 = not at all effective.

SCALE	1	3	5
	EXTREMELY EFFECTIVE	SOMEWHAT EFFECTIVE	NOT AT ALL EFFECTIVE

PUBLIC POLICY ACTIONS	
LIST OF INCENTIVES	MEAN RESPONSE
STATIONARY APPLICATIONS	
MICROGRID APPLICATIONS	
GOVERNMENT FUNDING FOR PROJECTS	1.8
INVESTMENT TAX CREDITS	2.5
RESEARCH AND DEVELOPMENT TAX CREDITS	2.6
PROPERTY TAX ABATEMENT FOR PURCHASER	2.8
SALES TAX ABATEMENT	3.1
INDUSTRIAL CUSTOMER-SITED APPLICATIONS	
GOVERNMENT FUNDING FOR PROJECTS	2.0
RESEARCH AND DEVELOPMENT TAX CREDITS	2.4
INVESTMENT TAX CREDITS	2.6
PROPERTY TAX ABATEMENT FOR PURCHASER	2.8
SALES TAX ABATEMENT	3.1
RESIDENTIAL CUSTOMER-SITED APPLICATIONS	
FEDERAL / STATE TAX CREDIT	2.2
SALES TAX ABATEMENT	2.7
ADVANCED POWER TECHNOLOGY DEVELOPMENT	
ADVANCED POWER TECHNOLOGY MANUFACTURING FACILITIES	
INVESTMENT TAX CREDITS	2.3
NIST COMMERCIALIZATION INCENTIVES	2.5
PROPERTY TAX ABATEMENT	2.8
ADVANCED POWER TECHNOLOGY R&D FACILITIES	
R&D FUNDING / INCENTIVES	1.8
INVESTMENT TAX CREDITS	2.4
TECHNOLOGY COMPETITIONS	2.5
PROPERTY TAX ABATEMENT	2.9

COMMENTS

- Government incentives should support development of technology that will stand on its own economically, not commercialization of technology that is not ready for market.

OTHER

- Stationary, microgrid applications: Production tax credits: 2

- Industrial customer sited applications: Production tax credits: 2
- Production incentives - Moving the incentive to "output" rather than investment is generally a better buy. With production, we at least get output and we don't pay!

STRATEGIC CONSIDERATIONS

Government funding for microgrid and industrial-sited advanced power technologies was rated as the most effective public policy action for encouraging the development of advanced power technologies. Many advanced power technologies are not yet commercially viable and, thus, are difficult to economically justify. Government support for initial application of these technologies is often critical. Yet, as the comment suggests, it is important that these projects highlight technologies that are beyond the experimental stage. This is important from both the standpoint of delivering a reliable source of energy and a positive introduction to the consumer for the new technology. The other listed policy actions for microgrid and industrial customer-sited advanced power technologies were considered at least somewhat effective by the panel.

Much attention has recently been given by states to attracting companies working on advanced power technologies and to encouraging the development of these technologies. The panel rates R&D funding and incentives as the most effective public policy for encouraging commercialization of advanced power technologies. Many of these technologies will not likely be commercially viable for several years. Their development will be costly, and given the decrease in venture capital in recent years compared with economic recession, funding for research and development is tenuous. The ability of governments to assist with funding is highly enticing. Yet, few in government, especially at the state or local level, have the technical expertise to identify and prioritize viable technologies. The challenge of identifying viable technologies and prioritizing high probability payoffs makes such a policy action difficult at best.

Property tax abatement, a common economic development tool, is rated as somewhat effective for encouraging R&D and manufacturing. However, each of the other listed policy actions is rated as more effective than property tax abatement. Although it is viewed as not as effective as the other alternatives, property tax abatements can be a much more acceptable form of incentive than the others because, it can be argued, tax abatements are merely not collecting taxes from operations that would not have located there without them, and the net effect is zero. Conversely, funding for R&D or manufacturing projects would be a direct and immediate outflow of money by the government and could be viewed by some as corporate welfare.

IV FUEL AND POWERTRAIN ISSUES

APTA-12 Please estimate U.S. retail fuel prices per gallon for 2007 and 2012, including fuel tax. (Please use constant 2001 dollars without adjusting for inflation).

UNLEADED GASOLINE	ESTIMATED 2001*	MEDIAN RESPONSE		INTERQUARTILE RANGE	
		2007	2012	2007	2012
UNLEADED REGULAR	$1.38	$1.50	$1.75	$1.50/$1.68	$1.75/$2.09
UNLEADED PREMIUM	$1.60	1.80	2.05	1.75/2.00	2.00/2.58

*D.O.E. 52 week average

COMMENTS

- If the Hubbert prediction holds, then in the more pessimistic case, I am low in my 2012 estimates.
- It is an absolute guess!! Nobody knows how the political environment will be at that time.

APTA-12a What percent of the change forecast in APTA-13 will be attributed to state and federal taxes?

PERCENT CHANGE ATTRIBUTED TO TAXES			
MEDIAN RESPONSE		INTERQUARTILE RANGE	
2007: 5%	2012: 10%	2007: 0/25%	2012: 5/50%

COMMENTS

- For the near term, I assume change is driven by taxes. In the long term, it will be fuel production that paces pricing.
- While increases in taxes are likely to increase fuel costs, increasing extraction and refining efficiencies will continue to drive fuel costs down.
- Taxes currently account for approximately 25 percent of the total price per gallon.

STRATEGIC CONSIDERATIONS

Respondents forecast an increase in the constant dollar price of gasoline in the coming decade. The political environment and the increased demand for oil from developing regions in the coming decade will likely place an upward pressure on the price of oil, as will political instability in oil-producing regions. Yet, as extraction techniques become more efficient or as increased price allows for methods not currently economical to be used, increased production will likely become available. The estimates suggest that gasoline, while more expensive than at present, will still be a rather inexpensive form of energy. It is important to note the interquartile ranges for the 2012 estimates. While the interquartile ranges vary by nearly one dollar for premium, they still suggest a relative confidence that a significant upward spike in prices is unlikely.

Panelists predict that only 10 percent of the forecasted increase in cost will come from increased taxation, although the interquartile ranges are somewhat wide. This suggests that panelists do not feel the government will seek to significantly influence vehicle choice through fuel pricing in the coming decade. Finally, the comment suggesting that estimating gasoline process is an absolute guess is somewhat correct. The expert panel survey process can best be described as what panelists (a group of identified experts) believe will happen, which is occasionally far from what does happen. And, while the panel has insight into the future price of oil, many also have direct input into resource allocation for new products and technology research and development. An important part of strategic planning in the automotive industry is based on the expected price of oil. Therefore, the forecast price of oil, even if somewhat of a guess, is a critical factor in determining where future resources will be allocated.

APTA-13 What percentage of light duty vehicles (including fleets) sold in the United States will use the following energy sources in 2007 and 2012?

ENERGY SOURCES	LIGHT DUTY VEHICLES			
	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2007	2012	2007	2012
GASOLINE	91%	83%	78/96%	70/87%
ALCOHOL OR ALCOHOL / GASOLINE (>10% ALCOHOL; INCLUDES FLEX FUEL OR VARIABLE FUEL)	2%	3%	1/5%	1/5%
DIESEL (INCLUDING BIO-DIESEL)	3%	10%	2/9%	5/20%
ELECTRIC (GRID-BASED)	0%	0.5%	0/1%	0/1%
HYDROGEN	0%	1%	0/0%	1/3%
NATURAL GAS	0.5%	2%	0/2%	0/3%

COMMENTS

- Gasoline will easily dominate the scene through 2030. By 2050 the alternative technologies will dominate the mix.
- Diesel in light trucks and fleets using natural gas will increase. Gasoline will still dominate in 2012.

STRATEGIC CONSIDERATIONS

The results suggest a continued dominance of gasoline through 2012. However, panelists indicate that several of the other listed energy sources will grow in use in the coming decade. Diesel fuel is forecast to increase to 10 percent of the light vehicle fleet by 2012. Alcohol/gasoline is also expected to increase. Hydrogen, natural gas and grid-based electric are expected to see limited application as a light vehicle energy source in the coming decade.

APTA-14 What percentage of light-duty vehicles (including fleets) sold in the United States will use the following powertrains in 2007 and 2012?

POWERTRAINS	PERCENT OF TOTAL FLEET			
	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2007	2012	2007	2012
THERMAL ENGINE-POWERED VEHICLES (INTERNAL AND EXTERNAL COMBUSTION)	98%	91%	95/99%	87/95%
HYBRID ELECTRIC VEHICLES (THERMAL COMBUSTION / ELECTRIC)	1.75%	7.5%	1/5%	4 /10.75%
FUEL CELL VEHICLES	0%	1%	0/0.5%	1/2%

COMMENTS

- I am basing my estimates on North American production of 16 million units. Of these, electric vehicles are approximately 10,000 (0.1 percent) and hybrids about 200,000 (1.2 percent).

OTHER

- Battery powered electric vehicles 2007: 0.2 percent; 2012: 0.4 percent

STRATEGIC CONSIDERATIONS

The thermal engine is forecast to continue to be the dominant power source for the coming decade. Hybrid electric vehicles are expected to see some penetration during that time period and the 12.5 percent (about 2 million vehicles in a 16-million unit market) estimate for the upper interquartile is worth noting. Panelists see initial application of fuel cells for light duty applications by 2012.

The thermal engine—more specifically, the internal combustion engine—will continue to offer a nearly unbeatable cost/efficiency/performance standard in the coming decade. Just as other advance powertrain technologies are seeing significant research and development effort, the ICE also continues to advance. APTA-1 addressed some of the more common technologies. Yet less visible, but equally critical, work is being done in the area of combustion chamber flow and design. Also, technologies such as homogeneous charge compression ignition (HCCI) engines exhibit significant potential.

These developmental efforts could have either a positive or negative impact on the future of hybrid vehicles. A super efficient/clean ICE could be viewed as a perfect partner for the electric motor to deliver truly outstanding emissions and mileage performance, albeit at a cost premium. Conversely, depending on gasoline prices and environmental issues, the same ultra clean/efficient ICE could greatly reduce the desirability of the more costly HEV. In fact, a case could be made that the ultra clean ICE may make the fuel cell and hydrogen engine irrelevant—or at least greatly delay their application in light vehicles.

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APTA-15 What percentage of thermal engine-powered light-duty vehicles forecast in question APTA-14 will use the following engines in 2007 and 2012? Please do not include hybrid electric vehicles in this estimate.

THERMAL COMBUSTION ENGINES	PERCENT OF TOTAL FLEET			
	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2007	2012	2007	2012
COMPRESSION ENGINE	5%	15%	3/20%	6/40%
SPARK IGNITED	95%	87.5%	80/97%	60/94%
STIRLING	0%	0%	0/0%	0/0%

COMMENTS

- My estimate of present compression ignition direct injection in North America is likely off since I'll assume less than 350,000 (2 percent).

STRATEGIC CONSIDERATIONS

The respondents continue to reinforce the strength of the spark-ignited (i.e., gasoline) engine. Yet, they also indicate that the compression (diesel) engine may gain significant application in the coming decade. In fact, given the current emissions challenges facing diesel technology, the forecast of 21.5 percent share by 2012 is somewhat interesting. APTA-1 indicates that the panel believes technology (direct injection, particulate traps and NO_x absorbers) will be commercially viable by 2012. Several states appear to be strongly opposed to diesel technology. However, recent pronouncements by the head of the California Air Resources Board are encouraging with regard to a closer examination of clean diesel technology. It will take a concerted effort to prove that the increased efficiency—and significantly reduced carbon dioxide emissions offered by diesel engines—will not be at the cost of locally increased particulate and NO_x emissions. Given the higher cost of diesel engines vis-à-vis gasoline engines, it is possible that a gasoline HEV will offer a more cost competitive solution than either the diesel or diesel hybrid. This is especially possible if diesel emission technology proves to be a high cost solution.

Panelists do not expect the Stirling engine to be a viable alternative in the coming decade. However, there is some interesting activity in this area. While it is likely that the Stirling may not be a viable technology within the next several years, it bears watching for future developments.

APTA-16 What percentage of hybrid electric vehicles forecast in question APTA-15 will use the following thermal combustion engines in 2007 and 2012?

THERMAL COMBUSTION ENGINES	PERCENT OF TOTAL FLEET			
	MEDIAN RESPONSE		INTERQUARTILE RANGE	
	2007	2012	2007	2012
COMPRESSION ENGINE	5%	10%	2.5/50%	5/48.75%
SPARK IGNITED	95%	88%	50/96.95%	50/95%
STIRLING	0%	0%	0/0%	0/0%

COMMENTS

- I do not see that compression ignition direct injection as a good match for hybrid vehicles in North America.

STRATEGIC CONSIDERATIONS

Although the respondents indicate that spark-ignited engines will be used in 90 percent of hybrid vehicles in 2012, the interquartile ranges suggest a great deal of uncertainty. A diesel HEV is a highly efficient powertrain. However, although more efficient than a gasoline HEV, the diesel has two significant disadvantages. The cost of a diesel engine is higher than that of a similar sized gasoline engine. The diesel with the added cost of hybrid electric vehicle motors and electronics may make such powertrain combinations too costly. Also, U.S. emissions regulations place a much higher emphasis on the reduction of particulates and NO_x than on the reduction of carbon dioxide—a critical disadvantage for the compression ignition engine.

It is important to note that European consumers have accepted the extra cost, as well as the issues surrounding particulate and NO_x emissions of the diesel. It is possible, even likely, that the diesel will be the engine of choice for hybrids in the European market, while the gasoline engine is the solution in the U.S. Such a split may have a detrimental effect on reaching global scale economies for hybrid components.

APTA-17 Please rate the severity of the following barriers to increased diesel engine application for light-duty vehicles, where 1 = a substantial barrier, 3 = somewhat of a barrier, and 5 = not a barrier at all.

SCALE	1	2	3	4	5
	A SUBSTANTIAL BARRIER	A BARRIER	SOMEWHAT OF A BARRIER	A SLIGHT BARRIER	NOT A BARRIER AT ALL

BARRIERS	MEAN RESPONSE
CURRENT EMISSION REGULATIONS	1.7
DEVELOPMENT OF TECHNOLOGY TO PROVIDE IMPROVED EMISSIONS	2.2
CUSTOMER IMAGE	2.3
MARKET VOLUME	3.2
MANUFACTURING INVESTMENTS (COST OF ENTRY TO MARKET)	3.3
NOISE AND OTHER REGULATIONS	3.6
FUEL COST AND AVAILABILITY	3.7
CURRENT EFFICIENCY REGULATIONS	3.8
DEVELOPMENT OF TECHNOLOGY TO PROVIDE IMPROVED EFFICIENCY	4.1

COMMENTS

- Modern compression ignited direct injection (CIDI) engines have performance equaling spark-ignited engines.

OTHER

- Additional cost of vehicle over gasoline version: 3

STRATEGIC CONSIDERATIONS

The diesel engine has gained popularity in Europe due to its excellent thermal efficiency and low carbon dioxide emissions. Many suggest that the technology presents an opportunity to increase the efficiency of the U.S. fleet. Application in larger vehicles, such as sport utility vehicles and pick-up trucks so common in the U.S. market, would allow for significantly increased miles per gallon, with a concomitant reduction in carbon dioxide. However, emission of particulates and NO_x, combined with consumer image are important barriers.

The panel indicates that consumer image of diesel engines is a barrier to increased application. Many consumers associate diesel engines with products that were on the market 20 years ago. During the energy crisis of the 1970s, several manufacturers offered diesel engines as an alternative to lower mileage gasoline engines. These engines were noisy, rough and generally not an acceptable alternative. Diesel technology has progressed greatly in the past few decades. The common rail direct injection products that are commonplace in Europe nearly match current gasoline engines in smoothness and offer significantly better torque. They also emit almost no smoke or odor. Many consumers would be challenged to notice the difference between the modern diesel and a comparable gasoline engine. Yet the image gained 20 years ago will be difficult to overcome.

The panel views the development of technology to meet emission requirements as an important barrier. While much work has been done in developing the modern compression ignition engine, much effort remains if it is to meet increasingly stringent emissions regulation. The development of common rail direct injection technology has allowed the diesel engine to meet performance drivability characteristics established by the spark-ignited engine. However, it has not completely resolved the emissions challenge. APTA-1 results suggest the panel believes that particulate traps and NO_x absorbers will be commercially viable in the coming decade. Such advances could lead to increased application of diesels in the U.S.

Finally, emission regulations present an important barrier to increased diesel penetration. Emission regulation has taken markedly different routes in the European Community, with its emphasis on reducing carbon dioxide, which is generally considered a greenhouse gas (Europe has chosen to focus on the global environment). The Europeans have used public policy to encourage the use of diesel engines. However, their focus on the global environment may be to the detriment of the local environment, via increased particulates and NO_x. Conversely, U.S. public policy has placed a higher priority on limiting the local environmental effects caused by diesel particulate and NO_x emissions and is less stringent on carbon dioxide emissions. A significant increase in diesel penetration in the U.S market will likely not come until either the technology exists to meet the U.S. requirements or there is significant agreement that global warming is a direct result of increased levels of carbon dioxide.