Automotive Technology: Greener Products, Changing Skills

Powertrain & Fuel Report

CAR
CENTER FOR AUTOMOTIVE RESEARCH

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Automotive Technology: Greener Products, Changing Skills

POWERTRAIN & FUEL REPORT

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1. Introduction

In the past 30 years, the motor vehicle has undergone a remarkable evolution. Nowhere is that evolution more apparent than in the vehicle powertrain. Yet, it is possible that the next decade may see an even more drastic evolution, even revolution, in technology. This report will highlight the types of powertrain technology under development, and possible timelines for the technology options and the workforce skills needed to research, develop and manufacture these products.

There is currently an enormous amount of excitement surrounding the electrification of the vehicle. During his election campaign, Barack Obama set a goal for the United States of one million plug-in electric vehicles (PEVs) on the road by 2010—a pledge he reconfirmed in the 2012 State of the Union speech. A review of general press reports might lead to the belief that PEV technology is going to be the dominant powertrain in the next five years. However, there are significant hurdles to the wide-scale penetration of PEVS, with cost being the most apparent. Numerous federal, state and local incentives have been developed to overcome the initial cost of PEVs; they are designed to reduce costs and increase public demand. Concomitantly, the incumbent powertrain technology—the spark ignited internal combustion engine—continues to evolve and improve. While it is likely that the trend toward vehicle electrification will continue, advanced powertrain technology options are many, though somewhat uncertain.

This report will also seek to identify powertrain-related skills and skill gaps, as well as jobs: those undergoing evolutionary change and those that are truly transformational. It is important to put changes in powertrain technology into context. The charge for this report was to define the change and job skills for a five- to 10-year horizon. Implementation of technology in the automotive industry—even the post-bankruptcy industry—can be relatively slow. Change comes over product cycles, which can be four or more years. Multiply that by product portfolios, and a completely new powertrain paradigm could take decades. Further, in many ways, it is a net-zero game. For example, the increased penetration of electric drivetrains may come at the cost of engineering and manufacturing for internal combustion engines—a strength of the Indiana, Michigan and Ohio region.

1.1 Methodology

Researchers at the Center for Automotive Research (CAR) investigated the general market for advanced and alternative powertrain technology and collected and reviewed articles, reports, and other documents on the current state of the technology, the market, and future trends. This report also relies on several advanced powertrain projects CAR has completed in recent years.[1]

[1] Smith, Brett C., Zachery Adams, and Jennifer Wong, *Powertrain Forecast and Analysis: What is Coming and What Are the Implications for the Specialty Equipment and Performance Aftermarket Industry*, (Ann Arbor: The Center for the Automotive Transportation, August 2009); Brett C. Smith and Chris Powers, *Automotive Powertrain Forecast, U.S. Market 2011 and 2016*, Prepared for The American Petroleum Institute, (Ann Arbor: The Center for Automotive Research, 2007).

For this report, CAR researchers sought input from representatives from the following companies and organizations. This input consisted of structured interviews, as well as lengthy less formal discussions.

- A123 Systems
- Bright Automotive
- Compact Power, Inc.
- DTE Energy
- Ford Motor Co.
- General Motors
- Grand Rapids (MI) Community College
- Think Automotive
- Toyota Motor Co.

1.2 Advanced and Alternative Powertrain Technology

In the past few years, the automotive industry has seen two federal energy directives: the Energy Independence and Security Act of 2007 and the subsequent National Highway and Transportation Safety Administration (NHTSA) Corporate Average Fuel Economy (CAFE) rules, as well as a ruling by the Environmental Protection Agency (EPA) stating that CO_2 is a harmful pollutant. Meanwhile, Congress continues to work toward a comprehensive energy bill, which some say may severely limit CO_2 emissions. Further, the administration has tasked the EPA with developing fuel economy standards through 2025. At the same time, consumers have seen gasoline prices vary from $1.50 per gallon to more than $5.00 per gallon; this instability makes optimizing new vehicle portfolios difficult.

In the automotive industry, uncertainty (in the market and/or in the policy arena) can be challenging, making these very uncertain times difficult for all manufacturers. The automotive industry has historically been somewhat risk averse. Given the enormous investment required for development and manufacture of its products, this is understandable. Yet, current market uncertainty makes almost all powertrain actions risky. Inactivity presents an equally risky strategy as does overinvestment in any one technology. The industry continues to develop new powertrain technology at a rapid rate; it is less certain how rapidly consumers will accept and embrace the new technologies.

The introduction of any new technology presents risks:

- First and foremost, there is the risk of introducing a technology which does not perform to the expectations of consumers and the marketplace. Examples of this are many, and include the General Motors diesel engines of the late 1970s as well as the Honda Accord HEV (which was biased for performance, not fuel economy). The widespread availability of a technology that does not meet customer expectations for performance and reliability, even if forced by regulation, can hurt a manufacturer's reputation and delay the technology implementation.

- Second, there is the risk of choosing the wrong technology or one with a very short market life. In these rapidly changing times, companies may chose what appears to be a viable technology, only to discover that advancement in another technology (or even a change in policy) can drastically alter the playing field. Some suggest that the modern diesel engine may be an example of the latter. Diesel technology appeared to be on the verge of broader application in the U.S. market in 2006 and 2007, with several companies announcing plans to build and market diesels. However, in the first half of 2009, several manufacturers cancelled or delayed their light-duty diesel engine programs. These changes were brought on (in part) by the economic crisis, but equally as much by the uncertainty surrounding the mid-term challenges diesel may have in meeting emissions standards.

It can be argued that, in regard to the automotive industry, there are currently too many technology options. The multitude of options, each with unknown future costs and technology synergies, present a strategic planning challenge for the industry—and educators. However, there is a general belief by interview respondents that the automobile will become increasingly reliant on electrification in the coming decade.

2. Advanced and Alternative Powertrain Options

The automotive industry is currently developing at least three key powertrain technologies: spark-ignited (gasoline) engines, compression ignition (diesel) and electric. Further, there are numerous variations on how these technologies are applied. For example, the hybrid vehicle combines an internal combustion engine with an electric motor. Refinements in one technology may have a strong positive (or negative) influence on another technology.

Current powertrain technology options include:

- Spark-ignited internal combustion engines (gasoline or E85)
- Direct injection
- Homogeneous charge compression ignition
- Compression ignition internal combustion engines (diesel or biodiesel)
- Hybrid electric vehicle (gasoline or diesel)
- Plug-in electric vehicles
- Plug-in hybrid electric vehicles
- Extended range plug-in electric vehicles
- Battery electric vehicles

This report is intended to investigate technologies that may affect job skill requirements over the next 10 years; therefore, it does not include a discussion of fuel cell technology. It is the opinion of the research team that, although development continues, fuel cells are not likely to be a mainstream technology within 10 years. It is likely there will be a limited number of high-skilled research and development jobs focused on fuel cell development in this time period; several outstanding education programs in the region can meet those needs. It is important to note that much of the work being done, and skills being developed, for HEVs and PEVs will be applicable to the fuel cell vehicle.

2.1 The Advanced Internal Combustion Engine

The internal combustion spark-ignited (SI—gasoline) and combustion-ignited (diesel) engines have been the power choice of the modern automobile for over a century, and will continue to be a cost-competitive bogey for other technologies.

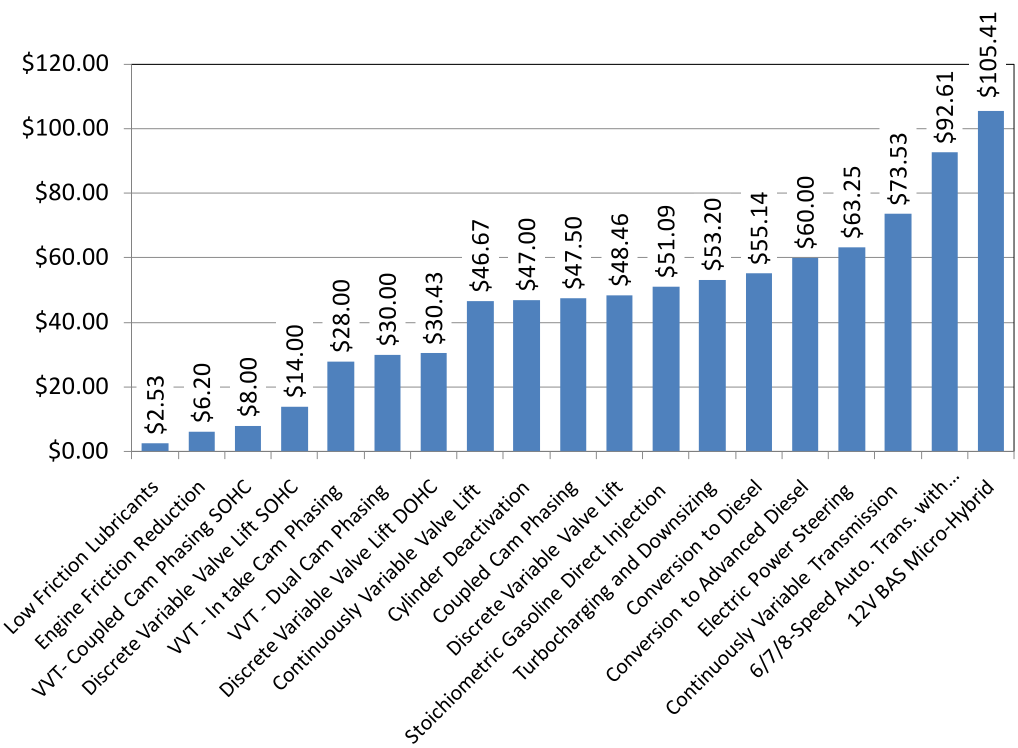
2.1.1 Spark-Ignited (Gasoline)

The gasoline engine will undergo significant development in the coming decade and will likely continue to be a significant power source for motor vehicles. The gasoline engine is the cost benchmark for all other technologies; it is also a moving target. In many ways, engineer of the spark-ignited engine occupy the original "green jobs" in the automotive industry: they have been refining the powertrain engine for decades—driven in large part by CAFE and emissions regulations. The modern day spark-ignited engine is a remarkably clean and efficient power source when compare to its predecessors of forty years ago.

In May 2010, the National Research Council (NRC) released an analysis of passenger vehicle fuel economy entitled Assessment of Duel Economy Technologies for Light-Duty Vehicles.[2] The report indicated that the spark-ignited engine will be the primary powertrain for light duty vehicles in the United States over the next 15 years.

There are *many* technologies that will play a role in making the gasoline engine more fuel efficient. Figure 1 shows the technologies identified in the NRC report. There are a couple of caveats regarding the technologies and the fuel economy estimates: first, they are not necessarily additive—their fuel economy gains cannot be added together to come up with a super-efficient engine. Second, the components illustrate there are multiple pathways to improved fuel efficiency, and some pathways may be more effective for different applications (i.e., small car vs. large truck).

Figure 1: Gasoline Engine Technology: Selected Technologies: Average Cost (dollars) per 1 Percent Fuel Economy Improvement



Source: NRC, 2010

Modern computing power has enabled engine developers to greatly increase the fuel efficiency of their product, and will continue to do so throughout the next 10 years. The ability to monitor

[2] National Research Council. (2010) "Assessment of Fuel Economy Technologies for Light-Duty Vehicle Fuel Economy." The National Academies.

in cylinder ignition has allowed for the implementation of previously highly challenging strategies. Gasoline direct injection (GDI) is an excellent example of this development. GDI is a strategy for increasing fuel economy, but without proper combustion management, can exceed emissions limits. Although GDI has been offered in other markets, until recently, the expectation for penetration in the U.S. market has been limited. Recent acceptance is due in large part to the ability to monitor the combustion process, thus minimizing emissions issues. To gain efficiency, engineers are trying to make the gasoline engine operate more like a diesel engine, and GDI is a step in that direction. Homogenous charge compression ignition (HCCI) is an even larger step toward that goal, however, HCCI presents equally large challenges. While several companies are actively developing the technology, it still remains a difficult strategy.

2.1.2 Compression-Ignited (Diesel)

The diesel engine has been far less successful in the United States than in Europe, where government policies have encouraged the use of the technology. Driven by emissions regulations and consumer choice, diesel technology has struggled in the U.S. market. However, compression ignition is a more efficient process, and offers fuel economy gains over the gasoline engine. The diesel engine has an advantage over gasoline engines in the following attributes:[3]

- **Fuel Economy:** Diesel engines are approximately 30 percent more efficient.
- **Power:** Diesels produce more power (and torque) at lower speeds.
- **Greenhouse Gases:** The comparable fuel efficiency of diesels permits the technology to produce lower greenhouse gases than for gasoline engines.

Diesel has a higher carbon to hydrogen ratio, thus emitting a higher amount of CO_2 per gallon of fuel. However, due to its higher energy content, diesel still offers CO_2 reductions vis-à-vis the gasoline engine. Diesel engines also emit higher NOx and particulates than gasoline engines, presenting significant challenges in meeting future emissions standards. Diesel engine fuel economy can be negatively affected by the addition of emissions reduction technologies. The added emissions control technology places the diesel engine—already more expensive than gasoline—at an even greater cost disadvantage.

2.1.3 Transmission Technology

The need for more efficient vehicles has also affected transmission technology.[4] Two key trends worth noting are the addition of more "speeds" and the increased interest in dual clutch automated manual transmissions. Manufacturers are increasingly using seven- and eight-speed transmissions to increase fuel economy. While these require more components, and subsequently more machining, there does not appear to be an associated increase in employment.

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[3] Intellitrends. (2008). "Diesel Engines: Market Review & Analysis."

[4] United States Environmental Protection Agency. (2009). Proposed Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards. Draft Joint Technical Support Document, U.S. Environmental Protection Agency, Assessment and Standards Division, Office of Transportation and Air Quality.

The dual clutch automated manual transmission is mechanically similar to a manual transmission, but does not require a manual clutch.[5] It offers the added fuel economy of a manual transmission without the need for the driver to operate a clutch. This technology change does not appear to increase production employment nor require additional skills.

2.2 The Electrification of the Vehicle

The electrification of the vehicle is happening—although perhaps not as quickly as some in the press and public office might suggest. It is important to understand how electrification impacts changes in powertrain technology.

The shift toward electrification can be separated into four distinct types of technology: hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), extended range electric vehicles (EREV) and battery electric vehicles (BEV). These technologies present (in order) an increasing reliance on electricity. The last three can be classified as plug-in electric vehicles (PEVs). These vehicles differ from internal combustion engine vehicles in that they require the management of high voltage; a skill critical to all PEV development is the power electronics or power conditioning. The automotive industry has not historically needed this skill set; thus, these skills have not been a focal point for the region's colleges and universities. Certainly there are exceptions—for example, Anderson, Indiana, is strong in power electronics, largely due to the product portfolio of companies and suppliers in the area.

2.2.1 Hybrid Electric Vehicles (HEV)

The hybrid electric vehicle combines an internal combustion engine and an electric motor. There are three basic variations: belt alternator starter (or mild hybrid), integrated generator assist and series-parallel. The three are presented from least to most expensive, and least to greatest efficiency gain. The Toyota Prius was the first high-volume series-parallel hybrid vehicle and has been on sale in the United States since 1997.

Because HEVs "blend" two powertrains, they require significantly more software code than vehicles relying solely on internal combustion (or even battery electric vehicles). Due to this blending, vehicle manufacturers have increasingly required their engineering personnel to develop a more comprehensive systems view of the powertrain. This ability for engineers to understand the entire system was cited as the single most important evolutionary skill required in the coming decade. In regard to the powertrain, the need for this broad systems skill can (in many ways) be traced back to the introduction of hybrid technology.

HEVs use nickel metal hydride batteries (NiMH) battery technology (see Figure 2). Manufacturing or assembly for this technology is not found in quantity in the tri-state region. Importantly, it is likely that lithium ion (LI-Ion) batteries will replace NIMH for some HEV applications over the next several years. Given the large amount of early generation LI-Ion battery production in the Midwest, this could be a very positive development.

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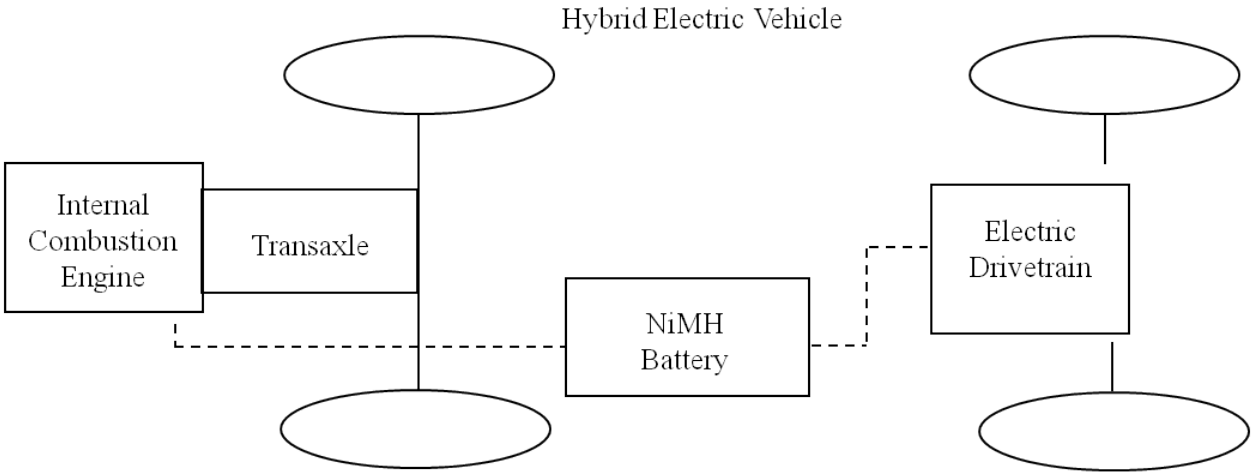
[5] Ibid.

Figure 2: Hybrid Electric Vehicle

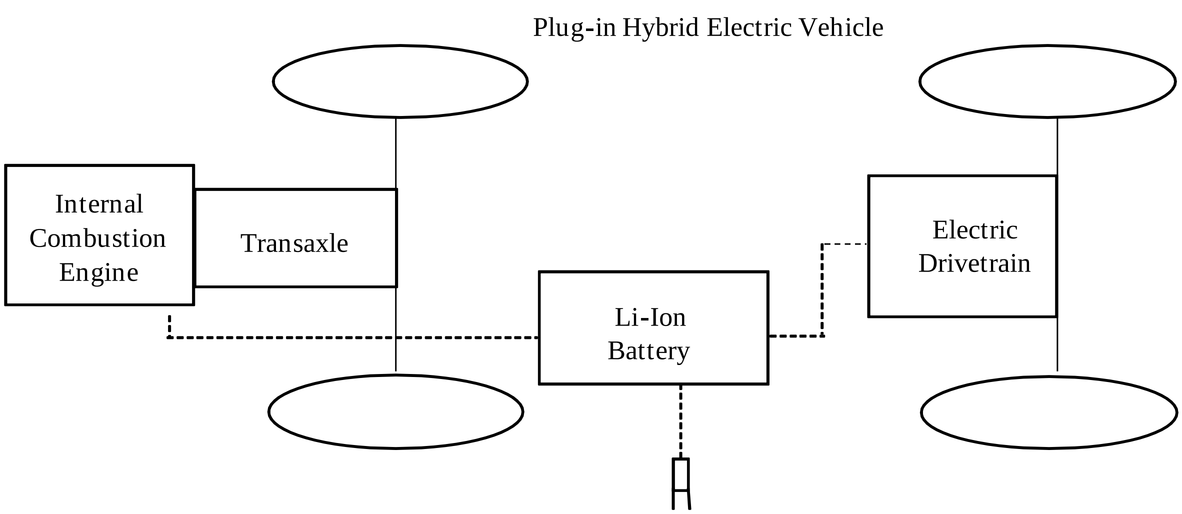


Source: Center for Automotive Research

2.2.2 Plug-in Hybrid Electric Vehicles (PHEV)

The plug-in electric vehicle can, in its simplest form, be described as an HEV with the ability to plug into an electrical engine for some portion of the outlet (see Figure 3). (An example of a PHEV is Bright Automotive's Idea delivery van.) PHEVs still rely upon the internal combustion drive cycle—specifically after the battery has reached a predetermined discharge level. The key differentiator between HEV and PHEV is the battery. As noted, current HEVs use a NiMH battery; however, PHEVs require the ability to access higher amounts of energy, and thus use lithium ion. When depleted, the battery can be charged either by connecting to the electrical grid or minimally by the gasoline engine.

Figure 3: Plug-in Hybrid Electric Vehicle

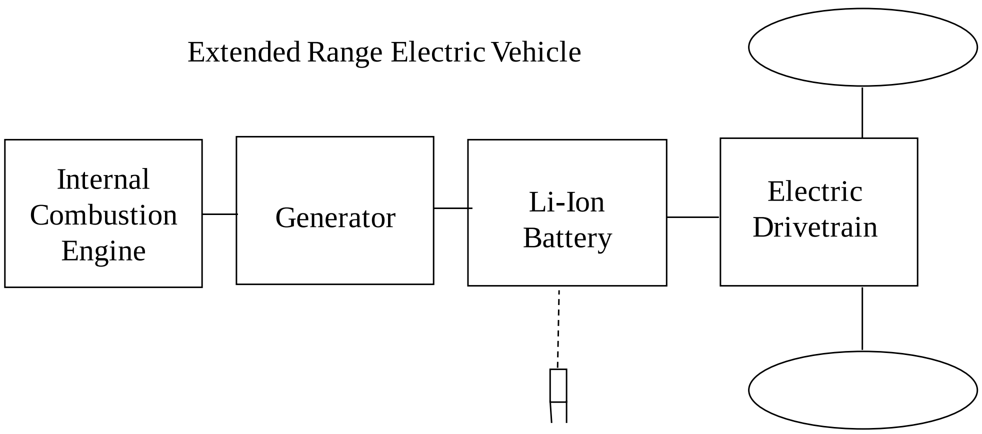


Source: Center for Automotive Research

2.2.3 Extended Range Electric Vehicles (EREV)

Similarly to the PHEV, the extended range electric vehicle utilizes a gasoline engine, an electric motor and a Li-Ion battery. The PHEV blends the gasoline engine and electric motor to power the wheels. Conversely, the EREV drives its wheels entirely (or almost entirely) via the electric drivetrain (see Figure 4). The gasoline engine powers a generator to create electricity, which is stored in Li-Ion battery. When depleted, the battery can be charged either by connecting to the electrical grid or by the gasoline engine. (The Chevrolet Volt is an example of this technology.) Because the technology does not require the blending of two powertrains to drive the wheels, EREVs may require less complex control strategies than HEVs and PHEVs.

Figure 4: Extended Range Electric Vehicle



Source: Center for Automotive Research

2.2.4 Battery Electric Vehicles

The battery electric vehicle contains an all electric drivetrain. The battery is charged by connecting to the grid. (Examples of BEVs are the Think City, the Ford Transit Connect, and the Nissan Leaf.) BEVs are currently limited by the range and cost of the battery.

2.2.5 Advanced Batteries

Advanced battery development has exploded in recent years, as has the publicity surrounding the technology. There are two key performance characteristics pertinent to the electrified vehicle: power, and energy. Power can be described as the ability to deliver electricity rapidly, while energy refers to the ability to store and release electricity.

As noted earlier, HEVs have relied on NiMH batteries for over a decade. HEV batteries operate in a narrower band than PEVs, with shorter cycles. Thus, they are optimized for power and not necessarily for energy.[6] The current NiMH battery technology meets those minimum requirements.

[6] Ibid.

PEVs will require higher power and significantly higher energy. Li-Ion batteries may offer the capability to double current NiMH performance characteristics and may be capable of meeting PEV performance requirements.[7] But the Li-Ion battery presents several technical risks for the vehicle manufacturers with energy density, production cost, and battery degradation viewed as the most challenging. Yet, there are many experts working at the vehicle manufacturers who see these issues as resolvable within the next *20* years.[8] Li-Ion is in the early development and production stage with much development remaining. The tri-state region has experienced early success in creating a Li-Ion manufacturing infrastructure. Subsequent sections describe the skills necessary for the advanced battery technology.

2.2.6 **Power Electronics for Vehicles**

The power electronics system—comprised of the DC/DC converter, the AC/DC power inverter and the control electronics for electric drivetrain—is another critical element of the electrified vehicle. The power electronics system is the controlling part of any alternative powered vehicle and, therefore, may be viewed similarly to ICE management software. The converter is necessary to convert power from higher to lower voltages; the inverter is necessary to convert the power from DC to AC for application in electric motors.

The development and manufacture of power electronics is a critical component in the electrified vehicle—from HEV to BEV (and even in fuel cell vehicles). Power electronics development has not traditionally been a strength of the domestic automotive industry; however, the defense and aerospace industries' research has lead to the creation of centers of expertise for power electronics far from the traditional automotive industry.

The tri-state region (with a few exceptions) is not currently a leader in the manufacture of power electronics. This has been reflected in the region's education systems, as well. In recent years, each of the vehicle manufacturers has worked to create power electronics expertise—primarily with internal resources. According to many respondents, it is a significant challenge to convince individuals from outside the region with expertise in power electronics to relocate. Therefore, power electronics is an important opportunity for education, training and retraining the region's workforce. It should be pointed out that several universities and community and technical colleges have been developing such programs over the past decade, yet much work remains to be done.

2.2.7 **Electric Drive Motors**

Electric motor technology is not new, but automotive applications are a relatively recent development. There are several manufacturers of electric motors for industrial applications.

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[7] Ibid.

[8] Smith, B., E. Ungar, and H. Mueller. (2010). *Benefits and Challenges of Achieving a Mainstream Market for Electric Vehicles.* U.S. Department of Energy, Vehicle Technologies Program and The Office of Electricity Delivery & Energy Reliability.

However, due to weight, packaging, higher specific power requirements and a broader operating range, these industrial motors are not necessarily suited for automotive application.[9]

Electric motors present a much more efficient means of converting energy to tractive force than the internal combustion engine. ICEs have efficiency ratings of between 20 to 30 percent; electric motors can reach 90 percent efficiency.[10]

The development of electric motors, while not as high or visible a priority as battery development, remains an important part of PEV improvement. Many initial PEVs use AC synchronous motors, but permanent magnet synchronous motors are increasingly being used. Work is also being done on switched reluctance motors and transverse flux motors.[11] The evolving technology for electric motors indicates the motor will be a critical development technology for the coming years—and another important opportunity for the region's educators.

There is some uncertainty with regard to the vertical integration of electric motors. Vehicle manufacturers will likely be closely involved in electric motor development—at least in the next several years. For example, Toyota continues to build the motor for the Prius, while General Motors will outsource the Chevrolet Volt motor for a brief time as it prepares for internal production. In recent years, General Motors has hired nearly 100 engineers to develop electric motors.[12]

2.2.8 **Charging Infrastructure**

A final technology to consider is the device used to connect the PEV to the electrical grid—the charger or charging station. There has been substantial research and effort put into understanding the technologies and strategies for connecting plug-in electric vehicles to the electrical grid; however, the components are similar to basic electrical smart grid technology and are not a particular strength of the automotive industry. There will be some new jobs associated with installation and maintenance of the chargers, both in residential and public places. Similar to smart grid technology, these chargers will require electrical utility technicians to develop electronic maintenance capabilities.

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[9] Valentine-Urbschat, Michael, D. W. (2009). *Powertrain 2020 - The Future Drives Electric.* Roland Berger Strategy Consultants.

[10] Electrification Coalition. (2009). "Electrification Roadmap: Revolutionizing Transportation and Achieving Energy Security."

[11] Valentine-Urbschat, Michael, D. W. (2009). "Powertrain 2020 - The Future Drives Electric." Roland Berger Strategy Consultants.

[12] Chappell, L., (2010, June 21). "Supplier Fumes as Carmakers take Electric Motors In-house." Automotive News, 4,18.

3. Alternative and Advanced Powertrain Technology Forecast

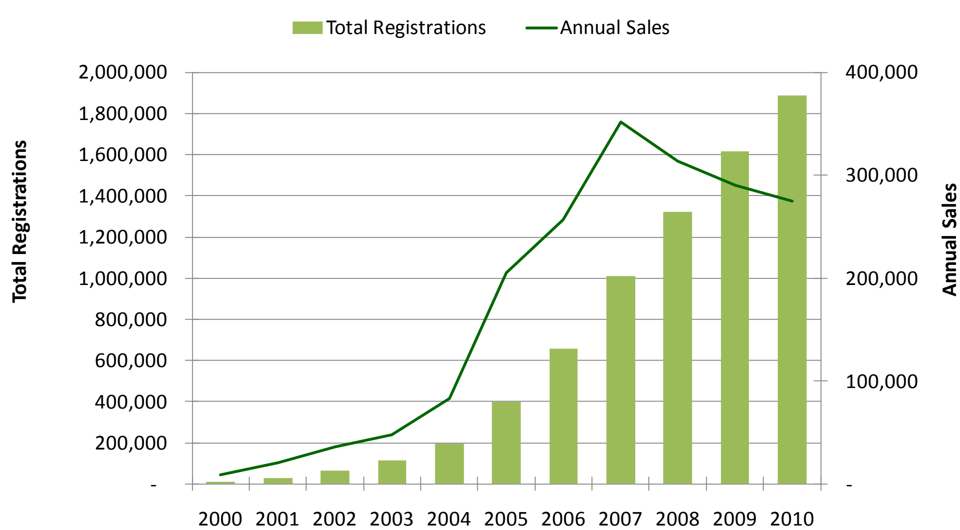
This report will focus on two considerations in the realization of alternative and advanced powertrain technology—type and time. As the Indiana, Michigan and Ohio region considers changes to the skills and education of the workforce, there must be consideration for the timing of when those skills will be marketable. The previous section addressed the types of technology under consideration. This section will investigate the potential timing of these new technologies.

3.1 HEV Market Penetration

Technology implementation in the automotive industry is, by nature, slow. The cost of components and development, as well as the industry's long product development process, force most technology revolutions to occur in what may appear to be more of a gradual evolutionary manner. HEV technology was first introduced into the U.S. market in 1977. Since then, there have been slightly fewer than 2.0 million HEVs sold (see Figure 5). Recent annual sales reached as high as 352,000 in 2007, but have fallen off during the recession, according to hybridcars.com.

Although HEVs represent strong fuel economy improvements, the vehicles do not appear to offer an inviting value equation for a strong majority of buyers. Recent U.S. sales performance of HEVs should serve as a lesson as the reader considers the future rate of market acceptance for all powertrain technologies.

Figure 5: U.S. Hybrid Vehicle Sales and Total Registrations, 2000-2009



Source: hybridcars.com

While technology implementation may be slow, it is critical to note that the skills required to bring this technology to market must be in place years before the vehicle reaches the consumer. In many ways, the demand for technical skills within the industry is not a reflection of current product mix, but rather the product mix expected three to six years in the future. The electrification of the vehicle requires some skills that were not previously in high demand. These new skill positions must be filled early in the product development life cycle, thus highlighting a need for immediate retraining or education.

The impact of technology on changing skills will be felt by more than those working directly on the vehicles. One industry executive put it succinctly: while there is uncertainty regarding the market share of HEVs/PEVs, her company fully expects the electrification of the vehicle to continue. Accordingly, she felt the change would impact the skills needed for at least 75 percent of their engineering and technical jobs.

3.2 Pace of Technology Implementation: Market Penetration

CAR has conducted several advanced powertrain technology surveys in recent years. This section presents the results of the most recent survey, a 2009 forecast for the Specialty Equipment Market Association (SEMA). Where instructive, results will be compared with earlier CAR surveys, as well as results from surveys conducted by others.

The study (conducted during the second quarter of 2009) presents results of a targeted survey of 17 powertrain experts from vehicle manufacturers, powertrain suppliers and powertrain engineering services firms. Most of the respondents had engineering backgrounds and were selected based on their wide range of expertise in both technical and market factors. This topic is highly complex in nature; as such, CAR believes there is a very small group of individuals capable of responding to such questions. We believe those who participated in this project represent an important segment of that small group.

Table 1 summarizes a forecast for 2011 and 2015 and offers two gasoline price options—$2.50 per gallon and $6.00 per gallon for two years (2011 and 2015). The authors believe these scenarios offer very different market challenges. For the brief duration of this forecast, the internal combustion engine will remain absolutely the dominant power source. It has been a focus of great development for more than 100 years; it appears that it will be further refined in the near-term.

Table 1: U.S. Market, Alternative and Advanced Powertrain Types, 2011 and 2015 (Percent total of U.S. Vehicles Sales)

	$2.50/ gallon		$6.00/ gallon	
	2011	**2015**	**2011**	**2015**
Dedicated Gasoline	91.5%	83.8%	89.0%	69.0%
Hybrid Electric Vehicle	5.0%	10.0%	6.0%	20.0%

	$2.50/ gallon		$6.00/ gallon	
	2011	**2015**	**2011**	**2015**
All Gasoline (Includes HEV and PHEVs)	96.5%	93.8%	95.0%	89.0%
Diesel	3.0%	5.0%	4.0%	7.5%
Battery Electric Vehicle	0.1%	1.0%	0.5%	2.5%

Source CAR/Specialty Equipment Market Association (SEMA)

There is great variation between the two price scenarios. The respondents' expectations for success—or failure—of any alternative and advanced powertrain technologies are based on economics. Their estimates make it clear that they believe the price of gasoline greatly affects the relative economic value of each powertrain option. What may not be as clear, however, is whether the consumer is able to make as concise a conclusion. After decades of relatively cheap gasoline, and the influence of other priorities in a vehicle purchase, a pure economic model may not apply to most consumer vehicle purchases.[13]

Clearly, fuel economy and the cost of vehicles is a rapidly moving target. CAR/SEMA respondents suggest that, even at $2.50 per gallon, 50 percent of gasoline engines sold in 2015 may be at least 20 percent more efficient than similar 2009 engines (see Table 2). Whether via downsizing and turbo charging, gasoline direct injection (GDI—with or without turbo charging), or even homogeneous charge compression ignition (HCCI), the gasoline engine will not stand still in relation to other powertrain technologies.

Table 2: U.S. Market, Percent of Significantly (20 percent over base) Improved Gasoline Engines, 2011 and 2015

	$2.50/ gallon		$6.00/ gallon	
	2011	**2015**	**2011**	**2015**
Percent significantly improved vis-à-vis current technology	10.0%	32.5%	10.0%	55.0%

Source CAR/SEMA

Those working on improving the fuel efficiency and emissions of the internal combustion engine *are* participating in the "green economy." While much interest has been focused on the electric vehicle sector as the "green" sector, the traditional supply base (developing the advanced ICE) has been creating more fuel-efficient products for decades. The work being done (as well as the skills being applied) at these companies is not revolutionary, but has been transforming over the past few decades. As the engine control module has become a more powerful computer, the skill set required has grown beyond that for a mechanical engineer. The current skill needs include not only a strong mechanical base but also an understanding of electronic controls and software.

[13] Tuuentine, T.S. and K. Kurani. (2006). "Car Buyers and Fuel Economy?" Institute of Transportation Studies, University of California. Davis, CA: Elsevier.

The CAR/SEMA survey forecasts HEV penetration for the U.S. market (see Table 3). The results appear to be somewhat optimistic and, as with all surveys, it is important to understand the environment at the time the questions were asked. At the time of this survey, there were several HEV products soon to be introduced. There was expectation that these products could possibly increase market share for the technology; in retrospect, that did not happen. If, as the forecast suggests, HEVs reach near 10 percent market share by 2015 (or 20 percent in the high gasoline price scenario), that will be a dramatic increase over the current share (roughly 2.8 percent).

Table 3: U.S. Market, Hybrid Electric Vehicles, 2011 and 2015 (Percent Total of U.S. Vehicle Sales)

	$2.50/ gallon		$6.00/ gallon	
	2011	**2015**	**2011**	**2015**
Hybrid Electric Vehicle	5.0%	10.0%	6.0%	20.0%

Source CAR/SEMA

Gauging actual PEV market volumes in the coming years is exceptionally challenging. A consumer listening to media—or the public relations announcements from some vehicle companies—might imagine the market for PEVs would soon reach well into the hundreds of thousands (even millions) of sales per year by 2012. Table 4 offers a potential scenario for PEV penetration based on the CAR/SEMA study. Using percentages of PEVs (as a percent of HEVs) and BEVs, with sales volumes of 12 million for 2011 and 14 million for 2015, and the two gasoline scenarios, we can derive an estimate of PEV sales. The estimates should be viewed with caution, but do offer an interesting approximation of potential volumes. Certainly a $6.00 per gallon gasoline price would likely have a strong negative impact on vehicles sales. Although vehicle sales have been held constant between the two gasoline price scenarios for this exercise, it is highly likely that at a higher gas price—either through increased oil prices, a gas tax, or some form of carbon tax—we would likely see a smaller overall market, and thus lower volumes, for all segments.

Table 4: Forecasted PEV Sales, 2011 and 2015

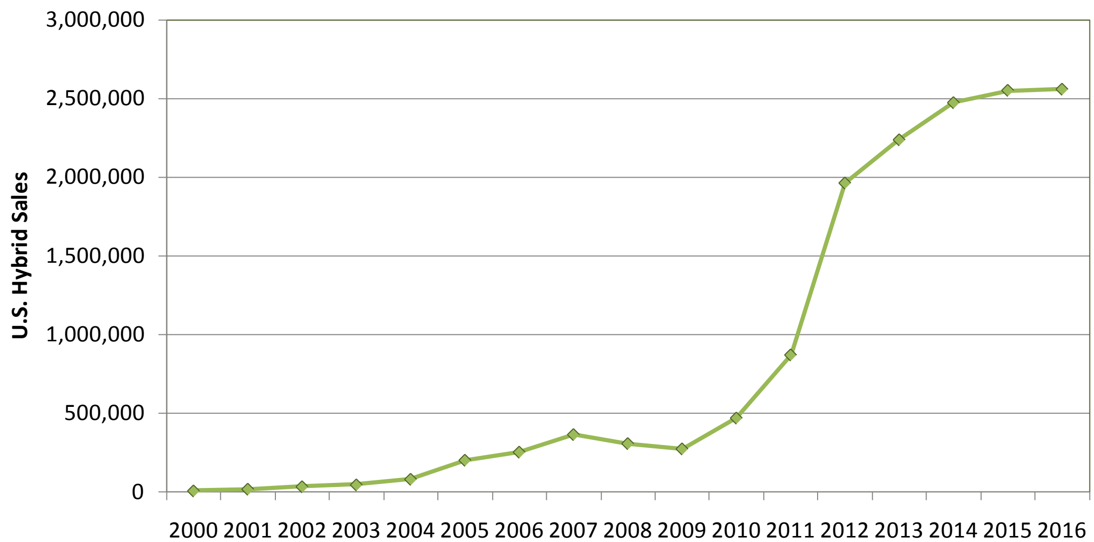
	$2.50/ gallon		$6.00/ gallon	
	2011	**2015**	**2011**	**2015**
U.S. Vehicle Sales	12,000,000	14,000,000	12,000,000	14,000,000
PHEV/EREV Sales	10,200	29,400	14,400	168,000
BEV Sales	12,000	140,000	60,000	350,000
Total PEV Sales	22,200	169,400	74,400	518,000

Source CAR/SEMA

There have been numerous other forecasts published. A forecast by Roland Berger Strategy Consultants includes two scenarios for 2015 and 2020. For their 2015 estimate, they forecast a market share range for PEVs of 0.3 percent (low) to 0.6 percent (high). Given a 15 million unit U.S. market, their estimate would equate to between 45,000 units and 90,000 units. Their forecast for 2020 is between 1.5 percent and 12.5 percent (225,000 and 1,875,000). An Oak Ridge National Laboratories (ORNL) report forecasts 425,000 PHEVs sold in 2015.[14] It is clear there is great uncertainty surrounding the market acceptance of PEVs.

Figure 6 shows the sales history and a forecast for traditional HEV and PEV powertrain vehicles in the United States. The overwhelming majority of sales are traditional hybrid vehicles, which continue to expand. From 2009 to 2016, the number of vehicles that rely at least in part on a battery for drive power is forecasted to increase almost tenfold, from just under 276,000 to 2,557,000.

Figure 6: U.S. Hybrid and Alternative Electric Powertrain Sales, 2000-2009 and 2010-2016 (Forecasted)



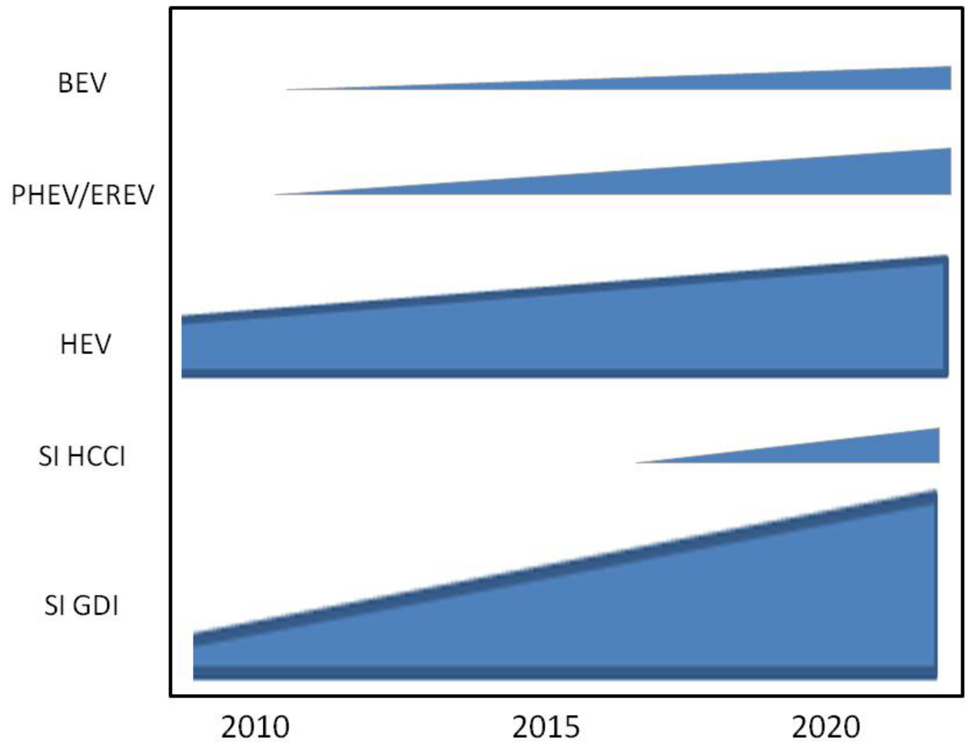
Source: IHS Global Insight, Inc. , Hybridcars.com "The Hybrid Report"

3.3 Alternative and Advanced Powertrain Market Penetration—a Summary

This report has highlighted key powertrain technologies for the coming decade. Figure 7 presents a timeline for their implementation. It includes two gasoline engine advancements (gasoline direct injection [GDI], and homogeneous charge compression [SI HCCI]), HEV, PHEV/EREV, and BEV. Figure 7 illustrates the breadth of technology options and the relative slowness of the market penetration. It is likely that GDI will see a growth rate of two to three times that of any other technology shown.

[14] Oak Ridge National Laboratory. (2010). "Plug-in Hybrid Electric Vehicle Market Introduction Study." U.S. Department of Energy, Oak Ridge, TN.

Figure 7: Alternative and Advanced Powertrain Technology Market Penetration, 2010-2020

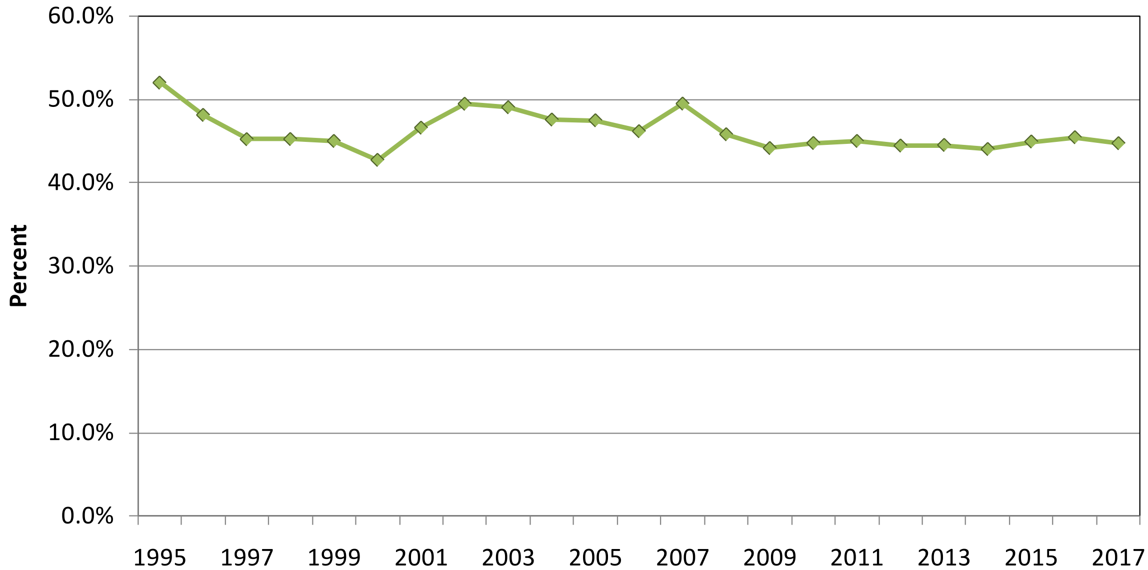


Source: Center for Automotive Research

3.4 Powertrain Jobs—A Zero Sum Game?

While the electrification of the vehicle is underway and its final form in the next decade is uncertain, a shift in technology will lead to a shift in employment. Figure 8 illustrates that the tri-state region has been, and is forecasted to continue to be, a major supplier of engines in North America. Any major developments in powertrain production will have a disproportional effect on employment in these states. A large scale displacement of traditional engine production by electric vehicle production could result in a negative net employment impact on the tri-state region.

Figure 8: Tri-State Engine Production as a Percent of Total North American Engine Production, 1995-2009 and 2010-2017 Forecast

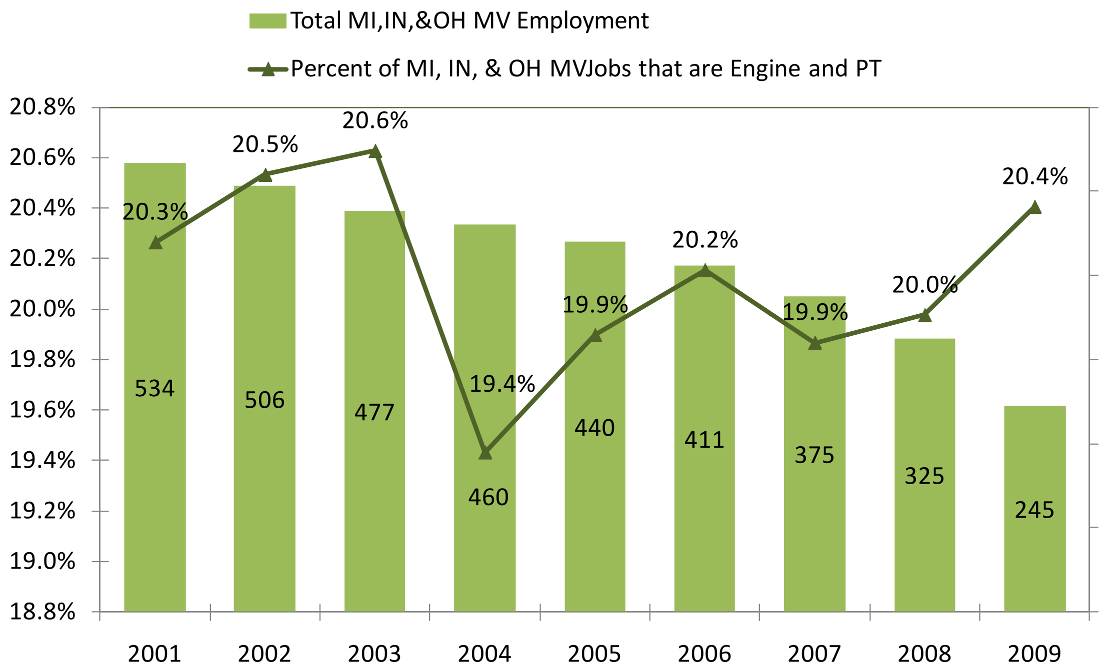


Source IHS Global Insight, Inc.

The expansion of traditional hybrid vehicle market penetration within the five- to 10-year time horizon is possible, and may not necessarily bode well for engine production employment in the tri-state region. Increased HEV penetration would include the expanded production of smaller engines for use in traditional hybrid vehicles, and the decreased production of larger engines. These smaller engines require hours per engine and, therefore, fewer workers than the engines used in traditional internal combustion-engine-only vehicles.

Figure 9 shows the tri-state region powertrain production employment as a percent of total automotive production employment. In 2009, the region had a higher percentage of automotive production workers (20.4 percent) in the powertrain sector than did the rest of the United States (15.6 percent). Within the region, Indiana had the highest proportion with 26.5 percent, Ohio had 19.4 percent, and Michigan had 18.1 percent.

Figure 9: Motor Vehicle Engine and Powertrain Employment in the Tri-State Region, 2001-2009



Note: Motor vehicle employment includes NAICS 3363 and 3361. Powertrain employment includes NAICS 33631 and 33635.
Source: Bureau of Labor Statistics

It is possible that EV propulsion systems may require fewer employees than the traditional engines and transmissions they would be displacing. Even if the production were to occur in the tri-state region, the net impact may be negative because fewer workers may be required to produce the same number of advanced powertrain propulsion systems.

There have been several announced Li-Ion battery plants (coatings, cell, and pack assembly) in the region. While the actual total future employment for these plants is somewhat uncertain, data gathered from corporate public announcements would suggest there could be well over 2,000 jobs when these plants grow to full capacity.

The tri-state region must prepare to make a strong push to capture both the engineering and manufacturing portions of the EV sector. However, assuming the technology succeeds in the market and there is a successful retention strategy leading to substantial new investment, EV engineering and manufacturing activity may not be sufficient to replace current jobs lost in the transformation.

4. Workforce Skills and Development

4.1 Skill Needs

4.1.1 Internal Combustion Engine (ICE) Engineering Skills

The skill sets for internal combustion engines are evolutionary in nature. It is important to note that those interviewed highlighted the fact that ICE development continues to be vital to the success of the industry and the region. It is possible that, over the next five years, there may be a slight increase in the number of engineers and technicians (mechanical and electronics) working on internal combustion engines. This is driven by increased federal fuel economy and emissions standards and the likelihood that future engines will have higher content, as illustrated earlier in Figure 1, to meet those standards. There are no new or evolving production skills considered unique to future ICE production.

4.1.2 HEV and PEV: Engineering Skills

All vehicle manufacturers continue to seek people skilled in software, power electronics and electro-mechanical engineering for work on HEV and PEV programs. When they have not been able to find such skills, some have created ways of developing them. One vehicle manufacturer has a high visibility partnership with a state university; others are rapidly following this model. The Energy System Engineering program at the University of Michigan includes graduate-level electric vehicle systems programs and has been an important part of General Motors' development of internal candidates. Several other tri-state region universities have similar programs in various stages of development, and the U.S. Department of Energy has awarded grants to Purdue University, Wayne State University, Michigan Technological University and the University of Michigan for Advanced Electric Drive Vehicle Education programs. These programs will be crucial in developing the skilled workforce for the electrification of the vehicle.

The vehicle manufacturers identified four key areas of need for engineering skills:

- Energy storage expertise (electrochemistry and chemistry)
- Power electronics engineering and development
- Motor engineering and development
- Powertrain systems engineering

According to most interviewed, these skills will be the drivers for future PEV development and will be in demand by vehicle manufacturers and suppliers alike.

4.1.3 Energy Storage: Manufacturing and Product Development

Battery production includes processes similar to chemical production processes (coatings, substrate manufacture and cell manufacture), those that rely on more traditional automotive type manufacturing engineering (pack assembly), and those that combine the two (cell manufacturing). There are skill sets unique to each of these processes, but all facilities require individuals skilled in working on equipment with high voltage—not unlike most other manufacturing plants.

4.1.4 Coatings Application Facility

Knowledge of material dispersion for mixing and coating was identified as a manufacturing engineering skill critical for the coating facility—a skill missing within the region. The coatings application process is highly precise and quality driven. Ideally, candidates will combine chemical engineering with manufacturing engineering skills. Due to the need for extremely high quality assurance, developers want to hire experienced candidates. This is expected to be an area of job growth in the coming decade.

4.1.5 Battery Pack Assembly Facility

There were few transformational job skills identified for the assembly of the battery pack. Much of the pack assembly process was described as using traditional advanced manufacturing engineering and production technology skills to create new assembly processes. This is an area of strong expertise for the tri-state region.

4.1.6 Cell Manufacturing Facility

Cell manufacturing combines skills traditionally found in the automotive industry with those traditionally found in the materials processing industry. One company expects candidates to have a Bachelor of Science degree in electrical, mechanical or manufacturing engineering, with five years of experience. Those with a combination of disciplines and clean room experience are even more highly sought-after.

4.1.7 Battery Product Development

The engineering of the battery combines skills found in chemical, electronics and mechanical engineering disciplines. One battery developer who recently hired product engineers indicated his company had typically considered only master's candidates with degrees in two engineering disciplines. These candidates were sought after because they could better understand the interaction between chemical, electronic and mechanical issues. The respondent also indicated these candidates were more likely to be capable of independent learning and problem-solving.

4.2 Job Skills and Employment Trends

Table 5 shows the SOC codes for selected job classifications; it also indicates the likely skill impact of alternative and advanced powertrain technologies on the workforce and whether there will be increasing or decreasing employment in that job classification.

Table 5: Alternative and Advanced Powertrain Technologies Skill Impact on Workforce and Expected Trend

Job Function	Associated SOC Codes	Description	Skill Impact on Workforce			Expected Trend
			Evolving	Additive	New	
Production	49-3023	Automotive service technicians and mechanics			X	Neutral
	49-3031	Bus/truck mechanics and diesel engine specialists			X	Neutral
	51-4034	Lathe and turning machine tool setters, operators, and tenders, metal and plastic		X		Neutral
	51-4035	Milling and planning machine setters, operators, and tenders, metal and plastic		X		Neutral
	51-4041	Machinists		X		Neutral
	51-4071	Foundry mold and coremakers		X		Neutral
	51-4072	Molding, coremaking, and casting machine setters, operators, and tenders, metal and plastic		X		Neutral
	51-4081	Multiple machine tool setters, operators, and tenders, metal and plastic		X		Neutral
	51-4111	Tool and die makers		X		Neutral
	51-4194	Tool grinders, filers, and sharpeners		X		Neutral
Manufacturing Engineer	17-2041	Develop processes for manufacturing chemicals and products			X	Increasing
	17-2112	Design/develop integrated systems for managing industrial production processes			X	Neutral
	17-2131	Evaluate materials and develop machinery and processes			X	Increasing
	17-3012	Design/develop electrical equipment for use in factories		X		Increasing
	17-3024	Operate, test, and maintain designing robotics equipment	X			Neutral

Job Function	Associated SOC Codes	Description	Skill Impact on Workforce			Expected Trend
			Evolving	Additive	New	
R&D Product Engineer	15-1031	Computer software engineers, applications		X		Increasing
	15-1032	Computer software engineers, systems software		X		Increasing
	17-2061	Computer hardware engineers		X		Increasing
	17-2071	Electrical engineers		X	X	Increasing
	17-2072	Electronics engineers, except computer		X	X	Increasing
	17-2141	Mechanical engineers	X			Decreasing
	17-3023	Electrical and electronic engineering technicians		X		Increasing
	17-3027	Mechanical engineering technicians	X			Decreasing
	19-2031	Chemists			X	Increasing
	19-2032	Materials scientists			X	Increasing
	19-4031	Chemical technicians			X	Increasing
	51-2022	Electrical and electronic equipment assemblers		X		Increasing
	51-2023	Electromechanical equipment assemblers			X	Increasing

4.3 Other Issues

4.3.1 Entrepreneurs

Similar to the automotive industry of 1910, there are many new entrepreneurs. The electrification of the vehicle has created an avenue for smaller, faster, entrepreneurial companies to compete—at least in the short run—with the industry giants. The tri-state region has seen several of these open operations within their borders. Over the coming years, some of these start-ups will make it to market with great products that capture market share and the imagination of a segment of buyers, but many will fade away.

Interviewees indicated these advanced powertrain technology starts-ups play a critical role in transforming the region's skill set. First, they are early buyers—albeit in low volumes—of "green" job skills. Start-up vehicle manufacturers are hiring and training engineering talent, blending the mechanical engineering skills of the traditional industry with the more advanced electrical engineering of the electrified vehicle. Second, according to many of the interviewees, the start-up companies are helping to create a new generation of entrepreneurs in the Midwest.

This region has a long history of entrepreneurs, including Eli Lilly, Henry Ford and Charles "Boss" Kettering. Yet, many of the respondents believe that entrepreneurship has faded in the last several decades. Although teaching and creating entrepreneurs cannot be considered a "green" job or skill, many of the respondents believe it is a critical element to the success of all companies in the region—big and small.

4.3.2 The Learning Culture

The need for all employees to be life-long learners is a message heard consistently throughout 15 years of CAR research on education and skills; this was confirmed in the interviews. It was pointed out that this is important for both the employee and the employer. For employees, it is likely job skills will evolve significantly over their careers, and they will need to adapt. For employers, the need for learning is driven in large part by the need to reduce management.

As noted previously, one battery developer indicated his company looks for individuals with at least a master's degree when hiring technical people. While this was in part due to the need for advanced and diverse technical skills, the respondent indicated he felt those with more advanced degrees were more likely to grow into self-guided problem solvers.

Another battery developer highlighted the ability to learn as important to a production staff. According to the respondent, people with these skills were highly valued because of their ability to work independently. However, the respondent indicated another important reason. The rate of change in battery manufacturing (cell and pack) is expected to be rapid in the coming years. Production employees must be capable of learning and refining new systems.

Conclusions

The electrification of the automobile is happening. However, the internal combustion engine represents a very difficult cost target, making it tough for other technologies to compete cost effectively. Even as the development of alternative forms of energy storage (batteries) is rapidly progressing, it is possible the ICE will remain the dominant technology for the next decade—and beyond. It is also possible that technology development may alter the cost equation.

Unique skills (e.g., increased chemical, electronic, and coatings expertise) were viewed as essential to the future of the industry. However, there was not a general consensus on the number of individuals with those skills that would be required. The most critical “unique” skill was that of systems engineering. It was ubiquitous throughout the responses. Although the mix of skills required by each company differed slightly, it was clear many engineering positions will require more than one discipline in the future. Those that require only one discipline will require (minimally) a more comprehensive understanding of the various subsystems. Industry respondents made it clear that educators must deliver technical graduates who are *topically strong* and systems savvy.

For the production skill worker, there were few skills unique to “green” manufacturing. The respondents did confirm the continued need to develop independent, life-long learners for all jobs. The production workers of the future will need to be motivated *problem solvers* that are willing to learn—with or without guidance—throughout their careers.