FINAL REPORT

Capstone Report - The Technology Readiness of Alternative Fuels

Alternative Fuels & Life-Cycle Engineering Program

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1 Executive Summary

The summation of the work done on the U.S. Department of Transportation (DOT) Alternative Fuels and Life Cycle Engineering Program is presented here in the form of a technology readiness assessment of alternative fuels. CIMS selected this methodology as the best way to represent the strengths and weaknesses of the fuels and technologies we evaluated, along with an easily understandable way to compare the fuels and technologies against each other.

As our research program developed, it became clear to us that whatever new technologies or fuels would be introduced to the U.S. marketplace, they would be evaluated through the lens of existing technology that had already been in use and fully adopted by the U.S. general public. The inertia to continue using petroleum-powered vehicles is extremely strong. Our lives are built around the car as we know it today. Shifting to some other product or fuel will require convincing the public that there is a significant benefit to adopting it. This benefit could be financial, environmental or social, or all three.

The other distinctive feature about petroleum powered vehicles is that there are, in rough terms, 240 million of them in the U.S. That number and that fact came to dominate our thinking about alternative fuels. Any attempt to make a significant dent in that number with alternative technologies requires significant time and resources.

To determine what it would take to move the public to these new technologies, we first had to understand them in as thorough a manner as possible. We wanted to acquire as much firsthand knowledge as we could given the time and resource constraints. Through literature research, we also identified areas where there were holes or gaps in knowledge about these new fuels and technologies and constructed a focused program to fill them. These objectives came together in the specific projects we established – evaluating ethanol and biodiesel in fleet vehicles, studying the impact of biodiesel on truck engines, constructing and operating our own hydrogen fueling station and vehicle fleet, evaluating the nascent electric vehicle choices and material and component analysis. Since fuels are part of a transportation system, we also spent considerable time talking with and listening to people on the front lines of the alternative fuel system – fleet operators, fuel producers, station owners, OEMs, hydrogen producers, government laboratories, component manufacturers, policy makers and consumers. Their impressions and real world experiences added to our own and informed our research results.

What we came away with is that, at present, there are several alternative fuels that "work" or can be made to work in the light duty vehicle fleet. Given time, the ingenuity and creativeness of American industry and the American public, they can be improved upon or made to work even better. It was also evident from our analysis that no one alternative fuel or technology will be the single 'drop-in' replacement for petroleum fuels. While each may have its own individual advantage, they also come with their own disadvantages. Time and more research can work to reduce those disadvantages. Ethanol can be made from non-food crops, but first someone had to determine if it would be effective and suitable in a vehicle, otherwise the research to find non-food sources would be wasted. Biodiesel is essentially a workable substitute for petroleum diesel, although there is some minor impact on performance. It can be made from waste oil, which does make it more sustainable.

Different regions of the U.S. may be able to capitalize on the advantages of type of energy over the other. For example, in the southwest, electricity produced from solar energy might make more sense to power plug-in vehicles. In the Midwest, biofuels might continue to be the right regional solution in flex fuel vehicles. In the northeast and northwest, hydrogen produced with electricity from hydropower might be the best value for hydrogen or fuel cell vehicles.

This reinforces the idea that a "broad front" national strategy for alternative fuels is a wise policy. Just because petroleum was our only fuel for a century does not mean it has to remain a single-product system. Diversification might in some ways be better – it softens the impact of international instability or natural disasters on one type of fuel or another. We also need to plan for the future with an eye to what has happened in the past. Those that ignore history are condemned to repeat it. As a nation we need to examine the pathway forward and ensure we don't work ourselves into another strategic dependency situation. Exchanging petroleum exclusively for batteries made from a strategic material such as lithium might also result in the same dilemma we find ourselves in today. A system with multiple pathways is more resilient.

That said, the major recommendation from the program is for more investment and research in bi-fuel vehicles until such time as the new fuels are determined to be fully effective and suitable and can stand alone. A second, corollary recommendation is to focus more resources on vehicle conversion technology to allow consumers to keep their existing vehicles while using new fuel sources.

2 Introduction

> *"This is the future of motoring. I'm absolutely convinced that the Honda Clarity Fuel Cell Vehicle is the most important car for 100 years. One day, we'll run out of oil. Then, sadly, we'll need something else. Think of all the people driving around out there. We've built our lives around the car as we know it. You get in, you drive as far as you want to go, you fill up, and you drive some more. That is the freedom that a petrol-powered car gives you. If it's replacement is something that only goes for ten yards and then takes four hours to bring back to life, we will have gone backwards. The Clarity is different. It fits the life we already have. The reason it's the car of the future is because it's just like the car of today."*
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> - James May, co-host of the BBC Television series *Top Gear*, reviewing the Honda Clarity Hydrogen Fuel Cell Vehicle, January 30, 2009.

In the four years that CIMS was engrossed in this alternative fuels program, we searched for a hook on which to hang the summation of our results. CIMS needed to find a theme to capture the significance of alternative fuel technologies on the U.S. transportation enterprise. With this series of statements about the Honda Clarity Fuel Cell Vehicle, we believe we have found it. The vehicles of the future have to be at least as good or better as the vehicles of today - we can't go backwards.

"One day, we'll run out of oil. Then sadly, we'll need something else." The 'something else' develop will either have to work just like petroleum, or better than petroleum. It may be a liquid fuel that has similar properties to diesel fuel and gasoline, or it can be a new, non-liquid fuel, but it had better be as easy to use as existing fuels, or it will be slow to be adopted.

"Think of all the people driving around out there." There are, conservatively, 246 million cars and trucks on the roads in the US right now, all running on some sort of petroleum based fuel. [1] Those

numbers do not include motorcycles, off-road vehicles, snowmobiles and lawn care equipment – all of which run on gasoline. 246 million samples of anything represents a lot of inertia for the status quo. Replacing those vehicles with new fuels or new technology will not happen overnight, or even in a decade. Even if it does, what do we do with all of them? Where do they all go? Can they still be used or converted? If a consumer has a classic 57 Thunderbird – will they still be able to drive it when the world goes all-electric or all-hydrogen?

"We've built our lives around the car as we know it." Nowhere is that more true than in the U.S. Our entire national character is inseparably intertwined with the automobile. Our homes, our jobs, our vacations, our childhoods, our holidays, our gift giving, our recreation are all linked in some way to the automobile. In the U.S., automobiles are not just big "appliances" like washers, dryers or refrigerators. Every American remembers their first car, does anyone remember their first refrigerator? Cars are much more important than that. They are not just transportation appliances that appeal to the head or the logic, they impact the soul and the emotions. Disconnecting that fact wholesale from the American character would be a near-impossible task. Alternative fuel vehicles that disturb this complex framework too much will not be adopted. People speak of changing the mindset in order to get the public to adopt new fuels and vehicles. For an item that is this linked to the soul of a nation, that change in mindset can only occur gradually, and maybe take a generation or two at least. And without a direct, immediate threat to gasoline and the internal combustion engine, the change will be slow indeed. Take for example the amount of change necessary to get millions of NASCAR or Formula 1 fans to come out to the raceway to see two dozen quiet little electric hybrids whizzing silently around the track.

"You get in, you drive as far as you want to go, you fill up, and you drive some more. That is the freedom that a petrol-powered car gives you." Not only the vehicles of the future must be as good as the vehicles of today, but the infrastructure must also seamlessly duplicate what we now have in place. Any infrastructure restrictions or constraints will impact the degree of freedom we already experience with "petrol" powered cars. Vehicles that offer lower cost or greater power must still offer equivalent range. If they don't, they won't be adopted. Range anxiety is a key factor in readiness to adopt these new technologies.

"If it's replacement is something that only goes for ten yards and then takes four hours to bring back to life, we will have gone backwards." As Americans, we have a visceral feeling that technology can solve all or most all problems. If we want to go to the moon, we invent some device or set of devices that makes it happen. If we want to power our vehicles with something other than oil, we should be clever enough to invent some set of devices that makes that happen as well. After all, we did go to the moon, and that was years ago, before cell phones were invented. Surely now we can come up with some sort of technological solution to the fuel crisis that won't affect how we go about our daily lives. Or, ideally, it should make our daily lives even easier, by making transportation easier, cheaper, cleaner or faster. Whatever solution(s) we arrive at, it can't possibly look as though we are going backwards. In the U.S., we are basically forward-looking. We won't accept a solution that offers otherwise.

"The Clarity is different. It fits the life we already have." The statement may be a bit premature considering the small number of hydrogen fueling stations, but the idea is not. Whatever our new solutions are, they must fit the life we already have. That life is structured around the automobile as we know it today.

"The reason it's the car of the future <u>is because it's just like the car of today</u>." All of our alternative fuel solutions, whether it's ethanol, biodiesel, hydrogen, natural gas, or electric are evaluated by

Americans against the background of a century of petrol-powered technology. For better or worse, consciously or subconsciously, the public will use the yardstick of what they have now in determining what they will accept in future vehicles. The cars of today are so deeply interwoven into our lives that replacing them with something else is not a trivial enterprise – nor is it a simple matter of logic and economics. "Will I be better off in five years than I am today? Will this vehicle cost me less overall to own than the one I have now? Can I carry as much, go as far, or as fast? Will my public image suffer or be enhanced as a result of buying it?"

This, then, is the essence of our alternative fuel program. The introduction of new transportation technology will be measured against the 246 million examples of existing technology. As researchers, it doesn't matter whether that is an appropriate criteria or not, the fact is we are dealing with a long-established consumer product and as long as Americans still have disposable income, they will buy what they want, not necessarily what is "better" for them. The auto industry group Edmunds predicts that although they have been available for many years, only 3.2% of 2010 auto sales of 11.5 million light duty vehicles will be hybrids.[2] That amounts to only 368,000 vehicles, which is only 0.15% of the U.S. light duty vehicle fleet.

Before these technologies such as flex-fuel, hybrids or fuel cell vehicles can be introduced to the mass market, they must be to some degree "ready" for consumer operation. In order for them to be adopted and successful, they must be usable by a wide range of drivers with different driving skills and experience levels. In order for them to be bought, they must be able to be operated. Designing a product that can be used (and maintained) by hundreds of millions of different users results in some compromises in technology insertion. Just as aircraft are not designed to be flown only by test pilots, automobiles must be designed for use by average consumers, not ace mechanics or Formula 1 drivers.

In order for us to assess the readiness of alternative fuel technologies, we needed to develop a set of universal criteria that could be used across the full spectrum of new technologies and address not only the vehicle itself, but the necessary fueling infrastructure and support structures. Hand in hand with development of the vehicles must be development and deployment of fueling stations, maintenance and repair centers and even disposal methodologies. Alternative fuel vehicles are at a level of development that is analogous to the development of the airplane a century ago – expensive, specialized technology that requires special support structures but only offers limited range and servicing locations.

Just as the airplane required construction of flying fields and maintenance stations to allow increased operation, so too do alternative fuel vehicles require investment in infrastructure. However, as aircraft offered a revolution in transportation due to increased speed and flexibility which incentivized their development, alternative fuel vehicles only offer a simple replacement for existing vehicles. Thus the "pull" of technology is not sufficient to spur significant investment in the infrastructure needed to support them. Consumers only get a substitute for what they have now, and what they are comfortable with. They get no increase in speed, extra parking spaces or reduced Thruway tolls for alternative fuel vehicles. They may even face higher total cost of ownership at this stage in development. So again, the significant hurdle of institutional inertia works against their adoption.

We have found through our research that for new technology to be adopted and used by the consumers, it must be seen as significantly *better* than what they have now.

In addition, as our final report was being formulated, the U.S. Government announced significantly stricter Corporate Average Fuel Economy (CAFE) standards and Greenhouse Gas Emissions levels. The new standards, covering model years 2012-2016, and ultimately requiring an average fuel economy standard of 35.5 mpg in 2016, are projected to save 1.8 billion barrels of oil over the life of the program with a fuel economy gain averaging more than five percent per year and a reduction of approximately 900 million metric tons in greenhouse gas emissions. This would surpass the CAFE law passed by Congress in 2007 (which) required an average fuel economy of 35 mpg in 2020.[3] Because of this aggressive mandate, auto manufacturers are now bound to devote their limited research resources to improving the existing internal combustion engine vehicles, at the expense of striking out on new pathways for alternative fuels.

With these constraints in mind, CIMS addressed the development of criteria for assessing the readiness of different alternative fuel technologies.

3 Technology Readiness Assessment

A central theme in many large scale system development projects, particularly in aerospace or defense, is that technology should be mature before advanced development and production begins. Normally, for technology to be considered mature, it must have been applied in a prototype article (a system, subsystem or component), tested in a relevant or operational environment and found to have performed adequately for the intended application. This implies a need for a way to measure the level of technology maturity and for a process to ensure that only sufficiently mature technology is used.

As applied in aerospace and defense, Technology Readiness Levels (TRL) are a set of nine graded definitions/descriptions of stages of technology maturity. They were originated by the National Aeronautics and Space Administration and adapted by the DOD for use in its acquisition system.[4] Versions of technology readiness ratings are used by various industries to evaluate their own system maturity. It is all part of a Technology Readiness Assessment (TRA). TRA is a systematic, metrics-based process that assesses the maturity of Critical Technology Elements.

Organizations use TRAs to ensure that technology employed in systems development is "mature" before full systems design begins. For example, for technology to be considered mature, a prototype article (system, subsystem or component) should be successfully tested in an environment that simulates what it will experience in actual service. For both the public and private sector then, there is a need to develop and implement a process to measure technology maturity. The outcome of this process is a finding of technical risk and guides the development agencies towards the answer of whether funding later phases of the development program are reasonable and affordable. Elements of technical risk also include designs, architecture, cost, schedule, and manufacturability. If the risk is too high, what further development is required to mature the technology to a point where the risk to program success is acceptable? History has shown that when programs have been initiated with immature technologies, the consequence had been enormous cost growth and significant schedule slips.

To conduct at TRA, organizations identify the critical technology elements of a system through an analysis of the program work breakdown structure. This analysis looks for technology components that are essential to the system and are either new or novel or a being applied in a new or novel way. The organization reviews the maturity of these elements against established requirements or metrics.

4 Transportation Technology Readiness Assessment

In the aerospace and defense world, system requirements are often very specific, the number of users is limited and the number of systems produced is also relatively small. In the automotive and transportation arena, the situation is almost the opposite: requirements are general and often subjective, and the number of users and systems produced is immense. Aerospace and defense systems often require extensive training before operation. Automotive systems, for the most part, do not. A new vehicle can be purchased and operated with only a cursory “walkaround” and a copy of an owner’s manual. Both sectors are subject to considerable regulatory compliance constraints (particularly safety and environmental), so the technology can only be implemented as fast as the regulations can keep up with it. Both sectors also require extensive operational and maintenance infrastructure to be effective and suitable for the users.

With that in mind, CIMS began with several existing aerospace and industrial technology readiness levels and criteria as guidance and developed a series of criteria of our own that we believe more accurately assesses the introduction of new automotive systems. The tools that are in use in government and industry have been adapted to apply them to the U.S. light duty transportation enterprise. Best practices from both have also been examined and incorporated where appropriate. CIMS spent considerable time developing what we considered to be accurate and comprehensive criteria – ones that incorporated both objective and subjective evaluations of technology. During this process, we balanced many factors – engineering capacity, strategic materials availability, consumer preferences and production capability. CIMS then applied these new technology readiness criteria to a number of emerging alternative fuel technologies in order to evaluate each against the others.

In developing these criteria we came to realize that automotive technology readiness is not composed of just the ability of the vehicle to accomplish its tasks. It also includes commercial readiness of the market to accept it, and consumer acceptance. Many of the subsequent criteria are objective, but some are necessarily subjective to account for these other factors. We believed that the criteria used for automotive systems needed to be broader than that for aerospace systems in order to account for intangible factors such as social acceptance.

The result is a set of standards which CIMS believes can be applied across the spectrum of new alternative fuel solutions and leads to the assessment of the possibilities of mass market acceptance of these new technologies. It is broken down into major groupings of vehicle technology readiness, commercial readiness, and technology societal impact.

The matrix, as developed, is meant to be a ‘living’ document. It is only a departure point to frame the discussion about what technologies hold the most promise to replace petroleum fuels and what level and concentration of research is needed to bring them to market. More categories could be added in the future as the range of alternative fuel options matures.

The flexibility of this assessment is also one of the key features of its overall utility. The other is that it allows decision makers to evaluate a range of technologies against each other. It builds a framework on which other technologies could be placed and evaluated.

4.1 Transportation Stages of Technology Maturity

- **Level 1: Unresolved (Concept) –** Technology has perceived benefit, but has not been shown to work for all required conditions.
- **Level 2: Low (Proof of Principle) –** Mathematical models and separate lab experiments have demonstrated technology viability in all required conditions.
- **Level 3: Moderate (Demonstration) –** Technology demonstration model has been built and successfully demonstrated requirements.
- **Level 4: High (Early Production) –** Product can be sold into limited markets with some compromise in performance.
- **Level 5: Very High (Low Volume Production / Market Penetration) –** Technology meets the needs of a specified market
- **Level 6: Criteria Met (High Volume Production / Market Acceptance) –** Technology meets market needs
- **Level 7: Market Requirement Exceeded –** Market differentiator

Each criterion was evaluated against the current level of technology maturity. Each level is defined separately for each criterion.

5 Transportation Technology Readiness Criteria

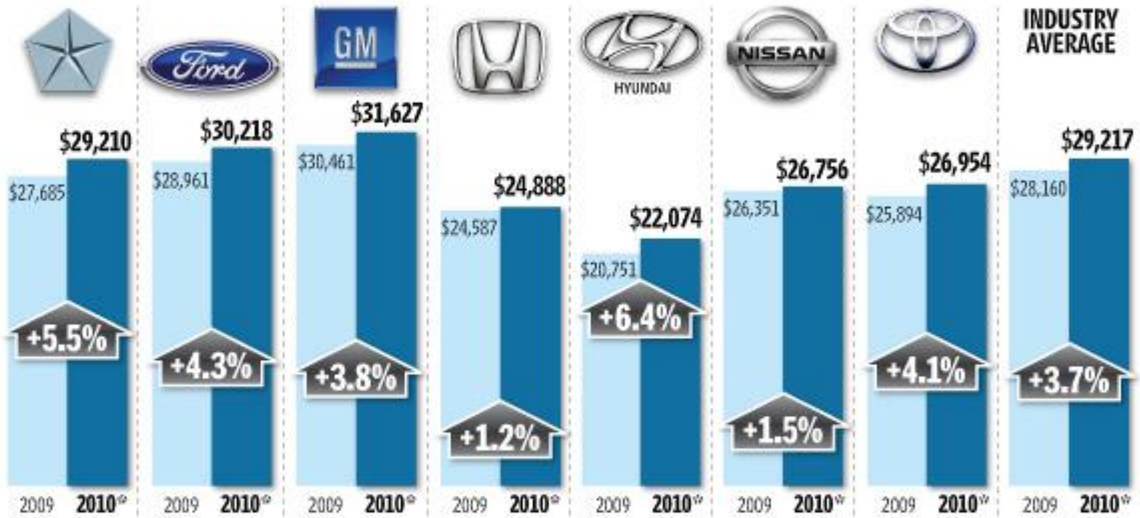
5.1 Vehicle Technology Readiness Criteria

The categories for the vehicle technology readiness criteria in Table 1 represent a broad range of factors that all have some bearing on the acceptance of new vehicle technology. Descriptions of each criterion and their significance are provided below. Primarily, the criteria are established with the existing light- to medium-duty gasoline and diesel fleets as the baseline.

5.1.1 Total Ownership Cost (TOC)

5.1.1.1 Vehicle Acquisition Cost (Table 1, Criterion 1a)

The largest single cost in TOC is the vehicle acquisition cost. This is the total purchase price of the vehicle, including sticker price, options and "buyer's premium" if applicable. It could also include the cost of a home fueling station, if that was available for a particular technology.



While sales of cars and trucks in the U.S. continue to be more sluggish than expected, automakers — especially the Detroit Three — are enjoying the largest increase in average transaction prices in more than five years. **Industry wide, consumers spent an estimated average of $29,217** on a new car or truck from January through May — an increase of $1,057, or 3.7 percent, compared to last year, according to estimates provided by Edmunds.com. Edmunds' estimate is based on a sampling of data from about 40 percent of U.S. dealers.[5] Note, this chart does not include European or other "high end" vehicles.

5.1.1.2 Fuel Economy/Cost per Mile (Table 1, Criterion 1b)

The most significant recurring cost that driver's are aware of is fuel and its effect on the likely amount of operational costs of the vehicle over its lifetime.[6] Unless maintenance or service costs are unusually high, the cost per mile is influenced most by the fuel economy of the vehicle.

Average Operating Costs Only per Mile

	Vehicle Type		
	Small sedan	**Medium sedan**	**Large sedan**
Gas and Oil	9.24¢	11.97¢	12.88¢

From American Automobile Association (AAA) report, *Behind the Numbers: Your Driving Costs*, 2009. Available at www.aaa.com/PublicAffairs.

5.1.1.3 Scheduled Maintenance/Service Cost (Table 1, Criterion 1c)

Maintenance or servicing costs for new technology vehicles could be prohibitive.[7] Beyond fluid and filter changes, does it require significant component or subsystem replacement on a regular basis that drives additional ownership cost? Does the vehicle require additional costly preventative maintenance over and above petroleum vehicles?

	Vehicle Type		
	Small sedan	**Medium sedan**	**Large sedan**
Maintenance	4.21¢	4.42¢	5.0¢
Tires	0.65¢	0.91¢	0.94¢

From AAA, *Behind the Numbers*, 2009.

5.1.1.4 Unscheduled Maintenance/Service Cost (Table 1, Criterion 1d)

Unscheduled maintenance cost reflects the costs of breakdowns or failures, even with a program of regularly scheduled preventative maintenance. There are few published statistics on the breakdown frequency of light duty vehicles so there is no "standard" to measure against. But with current technology vehicles, if the vehicle requires more than two or three unscheduled repairs per year, the owner is likely to perceive that the maintenance cost is prohibitively high. Even if the repairs are covered by the warranty, the cost to the owner of having the vehicle out of operation may be a factor if the vehicle is used for a business (work trucks, delivery vans, etc.)

5.1.2 Overall Vehicle Performance

It is taken as a given that all vehicle technologies will be able to perform similarly to vehicles within its vehicle class in order to be offered to the consumer. This includes acceleration and maximum speed, steering, and braking. Other criteria are listed below.

5.1.2.1 Single Fueling Fill up Maximum Trip Duration/Time Between Fill ups (Table 1, Criterion 2a)

The maximum trip duration, or range, is the maximum distance traveled on one fill up or fueling event, without any external support. An average range of 385 miles is calculated based on fleet wide average in-use fuel economy of 22.6 miles per gallon (mpg) for passenger cars as reported in the 29th edition of the "Transportation Energy Data Book," prepared for the U.S. Department of Energy, and an average fuel tank size of 17 gallons.

It is logical that as the vehicle fuel economy increases, that the trip range will also increase if there is no decrease in average fuel tank size. This was demonstrated by Volkswagen. The world record for trip duration on a single fill up was set in October of 2010 by the Volkswagen Passat at 1527 miles.[8] The Passat BlueMotion's fuel tank was drained before the record breaking journey and filled with 20.4 gallons of standard diesel, resulting in an overall fuel consumption of 89.83 miles per gallon. This substantially exceeds the Passat BlueMotion's official combined figure of 64.2 mpg.

5.1.2.2 Continuous Operation/Maximum Trip Duration (Table 1, Criterion 2b)

With the construction of the Interstate Highway System, the "road trip" is an ingrained part of American culture and the consumer considers the maximum driving distance as part of the purchasing decision. Though the majority of Americans will not be "cannonballing"[9] or driving cross-country non-stop, in a recent informal survey, nearly 85 percent of the 8,000 respondents to the AOL Autos survey replied that they have the desire to make the trip.[10] The vehicle continuous operating range is therefore similar to the top speed of a vehicle in that very few people actually experience the top speed, but an emotional connection and purchasing decisions are made based on the top speed.

More practically, the family vehicle is commonly used to travel long distances to visit the favorite vacation spot or to take the student back and forth to an out-of-state college. Also, domestic migration continues to redistribute the country's population.[11] With the spread of families across the country, it is culturally important to be able to travel and see family on short notice when other travel means might not be available. The vehicle should not be the limiting factor on how far a person travels in a single trip. (note that the refueling infrastructure is consider under a different criterion) If the trip is cut short due to vehicle requirements (charging, cooling, etc) then the consumer is forced to use additional vacation time for the trip, additional expense for lodging, or rent a vehicle that can make the trip. This criterion considers only the vehicle technology limitations on continuous operation.

5.1.2.3 Clean Air/Vehicle Tailpipe Emissions (Table 1, Criterion 2c)

Vehicles can pollute the air through combustion and fuel evaporation. These tailpipe and evaporative emissions contribute greatly to air pollution nationwide and are the primary cause of air quality problems in many urban areas. The EPA therefore regulates the emissions from mobile sources by setting standards on the amount of pollution a vehicle or engine can emit. Vehicles contribute to four significant air pollutants—carbon monoxide, hydrocarbons, nitrogen oxides, and particulate matter—as well as several other important air pollutants, such as air toxics and greenhouse gases.

All vehicles must meet or exceed current EPA emissions standards for its vehicle class in order for it to be sold commercially to consumers. (Note: this is for vehicle tailpipe emissions only, not life cycle emissions.)

Light-Duty Vehicle, Light-Duty Truck, and Medium-Duty Passenger Vehicle – Tier 2 Exhaust Emission Standards[12]

	Standard	Emission Limits at 50,000 miles					Emission Limits at Full Useful Life (120,000 miles)				
		NOx (g/mi)	NMOG (g/mi)	CO (g/mi)	PM (g/mi)	HCHO (g/mi)	NOx (g/mi)	NMOG (g/mi)	CO (g/mi)	PM (g/mi)	HCHO (g/mi)
Federal	Bin 1	-	-	-	-	-	0	0	0	0	0
	Bin 2	-	-	-	-	-	0.02	0.01	2.1	0.01	0.004
	Bin 3	-	-	-	-	-	0.03	0.055	2.1	0.01	0.011
	Bin 4	-	-	-	-	-	0.04	0.07	2.1	0.01	0.011
	Bin 5	0.05	0.075	3.4	-	0.015	0.07	0.09	4.2	0.01	0.018
	Bin 6	0.08	0.075	3.4	-	0.015	0.1	0.09	4.2	0.01	0.018
	Bin 7	0.11	0.075	3.4	-	0.015	0.15	0.09	4.2	0.02	0.018
	Bin 8	0.14	0.100 / 0.125[c]	3.4	-	0.015	0.2	0.125 / 0.156	4.2	0.02	0.018

5.1.2.4 Geographic Operating Restrictions (Table 1, Criterion 2d)

In order to be commercially viable, vehicles should be able to operate anywhere in the United States without any geographic restrictions such as heat, cold, moisture, and altitude. The vehicle operating window was therefore defined by considering the conditions experiences in the US.

Trail Ridge Road is the name for a stretch of U.S. Highway 34 and is the highest continuous highway in the United States. Also known as Trail Ridge Road/Beaver

Meadow National Scenic Byway, it traverses Rocky Mountain National Park from Estes Park, Colorado in the east to Grand Lake, Colorado in the west. It reaches a maximum elevation of 12,183 ft (3,713 m).

International Falls Minnesota has long promoted itself as the "Icebox of the Nation". It experiences an average January low temperature of -8.4 °F (−22.4 °C), with a record low of -55°F (−48.3 °C).

Death Valley is a desert valley located in Eastern California and is the lowest (282 feet (86.0 m) below sea level), driest, and hottest location in the United States. Death Valley holds the record for the highest reliably reported temperature in the Western hemisphere at 134 °F (56.7 °C)

The FreedomCAR and vehicle technologies multi-year program plan for 2006 sets two temperature targets: -30°C to +52°C operating temperature, and -46°C to +66°C survival temperature.[13] Vehicles which operate in Northern Tier states and Alaska now routinely use engine block heaters in the winter months, so inclusion of these in the design would meet existing consumer expectations.

5.1.3 Vehicle Usability

5.1.3.1 Vehicle scheduled service interval (scheduled time in repair) (Table 1, Criterion 3a)

Calendar time or miles between regular service or preventative maintenance events is comparable to other vehicles in the class.

The most common preventative maintenance event is oil change. For vehicles that still use lubricating oil, an interval of 5000 miles per event is now standard and currently increasing. For vehicles that do not require lubricating oil, the next required maintenance event such as tire replacement or coolant change would be the driving factor. With an average annual driving mileage of 12-15000 miles, this would mean a maximum of three scheduled maintenance events per year to be comparable to other vehicles in the class.

"Carmakers increase oil change intervals: Improvements in lubricants, engines extend guidelines

By Tom Krisher, Associated Press, April 1, 2007

"DETROIT -- Most major automakers agree: The adage that you should change your car's oil every 3,000 miles is outdated, and even 5,000 miles may be too often. Ford Motor Co. became the latest manufacturer to extend its oil life guidelines, making public that it is raising the recommended oil change interval from 5,000 miles to 7,500 on its newly redesigned 2007 models and all subsequent redesigned or new models. Some manufacturers, such as Honda Motor Co. and General Motors Corp., have stopped making recommendations on all or most of their models, instead relying on sensors that measure oil temperature extremes and engine revolutions over time to calculate oil life and tell drivers when to get the lubricant changed. Oil can lose its lubricating properties if it runs at too low or too high a temperature. General Motor's Oil Life System alerts drivers when it is time to change the oil. Higher-quality oils and better engine technology have raised engine oil replacement intervals in recent years. Peter Lord, executive director of

GM's service operations, said oil can last 12,000 miles or even more for many drivers who don't run their vehicles in extreme heat or cold or tow heavy loads."

5.1.3.2 Vehicle fueling operability/fill time (Table 1, Criterion 3b)

Time required to fill vehicle from empty or depleted to full fuel capacity. This is the most significant periodic servicing event in the vehicle life cycle. It is also a function that must be performed by the owner/operator on a daily or weekly basis, thus requiring a time budget since it is usually accomplished away from home and in conjunction with other activities (commuting, shopping, vacationing).

Although there are no published studies on this particular function, anecdotal information indicates that the fill time for current technology liquid-fueled vehicles is no more than 10 minutes for large capacity fuel tanks, but averages 5 minutes or less per fueling event for cars and light trucks.

5.1.3.3 Refueling system (vehicle side) design stability (Table 1, Criterion 3c)

The interface between the vehicle and the refueling system has been firmly defined and remains essentially unchanged during the vehicle service life.

This criteria evaluates the extent to which standards have been developed and implemented for the fueling/refueling system and interface between the infrastructure and the vehicle. As the vehicle system transitions from the developmental to the production phases of its life-cycle, there should be a "freeze" on the configuration of the interfaces with the infrastructure so that vehicle components can be produced in mass-production volumes. This also allows for production and widespread implementation of new fueling infrastructures if required.

5.1.4 Safety

5.1.4.1 Vehicle operational safety (Table 1, Criterion 4a)

The National Highway Traffic Safety Administration has a legislative mandate under Title 49 of the United States Code, Chapter 301, Motor Vehicle Safety[14], to issue Federal Motor Vehicle Safety Standards (FMVSS) and regulations to which manufacturers of motor vehicles must conform and certify compliance. These federal safety standards are regulations written in terms of minimum safety performance requirements for motor vehicles or items of motor vehicle equipment. These requirements are specified in such a manner "that the public is protected against unreasonable risk of crashes occurring as a result of the design, construction, or performance of motor vehicles and is also protected against unreasonable risk of death or injury in the event crashes do occur."[15]

Beyond the vehicle safety required by the standards, the New Car Assessment Program (NCAP) is a 5-Star Safety Ratings System created by the National Highway Traffic Safety Administration (NHTSA) to provide consumers with information about the crash protection and rollover safety of new vehicles. One star is the lowest rating, five stars is the highest with more stars indicating safer vehicles.[16]

5.1.4.2 Fuel Operational Safety, Human Health (Table 1, Criterion 4b)

Where public safety is primary, the authority having jurisdiction (AHJ) may be a federal, state, local, or other regional department or individual such as: the fire chief, fire marshal, chief of a fire prevention bureau, labor department, or health department, building official, electrical inspector, or others having statutory authority. Typically, state and local governments (zoning, building permits) are the AHJ for fuel dispensing and fuel storage operations, and standards development organizations (SDOs) are responsible for leading the support and development of key codes and standards for alternative fuel vehicles, dispensing, storage, and infrastructure.[17] Fuel storage and dispensing equipment for all alternative fuels have to meet safety requirements prior to being allowed to operate. Therefore, even though fuel storage and dispenser safety is critically important and required, it is not a differentiator between fuels and is not used as a technology readiness criterion.

Dispenser operational safety however can be differentiated by identifying the level of skill required to operate and whether the dispensing equipment can be operated safely by the general public. Some AHJ for example require that self-service pumps available to the general public have safeguards to prevent flammable fuel from being obtained by minors, intoxicated persons, or persons seeking the fuel during a time of civil disorder.

Notably, however, other than as part of the curriculum for a driver education program, no fueling training is required of current technology vehicle users. And in spite of placards and warnings at service stations and convenience stores, contemporary users still fill their vehicle while it is running, while talking on mobile phones, or engaged in other activities.

5.1.4.3 First Responder Safety (Table 1, Criterion 4c)

The scene of any vehicle accident is often chaotic and it is imperative for first responders to work within the constraints of a critical timeframe to ensure their safety and the safety of accident vehicle occupants. New vehicle technology must therefore consider the training and safety of emergency response personnel in case of an accident. If the vehicle type or fuel type is obscured due to damage or debris, emergency personnel must be able to render the fuel system "safe" in a range of situations in order to tend to the injured.

The vehicle must therefore provide a level of safety protection to allow emergency personnel to extract drivers in case of a mishap and render the vehicle safe for towing, maintenance or disposal. Also, procedures must be developed for these situations and provided to first responder organizations. These standards are currently developed by the National Fire Protection Association (NFPA)[18]; however, there are various levels of dissemination, required skill, and awareness depending on the technology.

5.1.5 Vehicle Production Technology

5.1.5.1 Vehicle production volume (Table 1, Criterion 5a)

The vehicle design sufficiently mature to implement a production program. This can either be a low-rate initial production or immediate implementation of full mass production rates.

Manufacturing readiness and producibility are as important to the successful development of a system as are the readiness and the capabilities of the technologies intended for the system. Prototypes are often built by methods that are not suitable for production, so the testing of prototypes does not usually tell much about the maturity of the manufacturing technologies that must be used to achieve the production rate, production cost, and low defect rate that are needed. Indeed, prototypes are sometimes "hand built" using skill sets, techniques or tooling that are not designed for or directly transferable to rate production.

At the low-rate production point, the maturity of a manufacturing technology should be as follows:

- Manufacturing processes, materials and assembly methods have been developed for a production environment—ideally in a pre-production facility or better.
- The design is maturing, key materials and process characteristics have been identified, and planning is taking place for managing process controls, as appropriate.
- A detailed manufacturing risk assessment has been performed. This assessment covers industrial base infrastructure (facilities and manpower), materials (availability, producibility characteristics), methods (mature processes), measurement (inspection and test equipment), and costs.
- A quality management structure has been identified.
- Initial goals have been set for yields, quality, and reliability.
- Plans for configuration and block change management.
- Supply chains established for subcomponents.

Full rate production should not be initiated if a critical manufacturing technology has not been successfully qualified through test and demonstration. This implies the following:

- Manufacturing processes, materials, and assembly methods demonstrated on production-representative articles with no known significant manufacturing risk.
- Tooling is robust enough to handle rate production.
- Yields, quality, and reliability within 25 percent of goals.
- Design mature (process requirements proven and validated).
- Quality management structures in place.

Source: *Department of Defense Technology Readiness Assessment Deskbook*, May 2005.

5.1.5.2 Availability of critical materials for vehicle production (Table 1, Criterion 5b)

The vehicle components are not fabricated from "strategic materials", i.e., materials that are scarce, or located in unstable regions of the world.

The entire premise of this assessment is the evaluation of fuels that can replace petroleum which is increasingly hard to acquire due to environmental concerns, government prohibitions or regional instabilities. Selection of a replacement technology that presents the same problems will not offer a reasonable solution. Evaluation of the material contents of the system must proceed in parallel with development and testing.

Key issues for evaluating Critical Materials include:

- Availability and degree of competition
- Sources (domestic/foreign/single/sole/diminishing) and Make/Buy Plan
- Use of commercial-of-the-shelf/non-developmental items/commercial items
- Costs, lead times, and capacity constraints and scale-up challenges
- Understanding materials' basic properties and environmental considerations
- Characterization in a manufacturing environment
- Storage, handling, and parts control

5.1.5.3 Technology readiness of vehicle maintenance and support structure. (Table 1, Criterion 5c)

Is the additional repair infrastructure, support equipment, spare parts and maintenance training are in place to support the production and deployment of the vehicle to the public.

In order to successfully deploy a new technology vehicle to the public, the maintenance and repair concept must be defined. Then the necessary maintenance support equipment must be developed. This effort encompasses all the procedures and techniques used to determine requirements for and to acquire the fixed and mobile equipment needed to support the operations and maintenance of a system. This includes tools; test, measurement, and diagnostic equipment (TMDE); calibration equipment; prognostics/imbedded diagnostics; and automated test equipment (ATE).

5.1.6 Fueling Infrastructure Technology

5.1.6.1 Long term fuel stability, storage life (Table 1, Criterion 6a)

Any new fuel must have sufficient stability and storage life for a nation-wide deployment, storage in dispensing facilities, and storage and use in vehicles. Gasoline and Ultra Low Sulfur Diesel are used as the benchmarks for this criterion. Petroleum fuels long term storage is highly dependent on the fuel formulation and the storage conditions such as temperature, exposure to light, and level of sealed container. There is therefore no published standard gasoline shelf life. Anecdotal evidence suggests that a commonly accepted gasoline shelf life is between three and six months. This relatively short shelf life has given rise to a fuel stabilizer market in which products such as STA-BIL® claim to extend the shelf life of gasoline to one year[19].

Another consideration for fuel storage stability is for those "seasonal" users who will use the fuel along with the highway transportation sector. Motorcycle, marine and lawn equipment that currently runs on gasoline are traditionally stored for as long as six months with fuel on-board over the winter months. Consideration must be given to those operations also if a liquid fuel will be replaced by a different technology across the board.

5.1.6.2 Station Technology / Infrastructure cost (Table 1, Criterion 6b)

The capital cost of a station can range from adapting existing gasoline or diesel equipment to ensure compatibility with ethanol or biodiesel, to installing a completely new station with pressurized storage tanks and adequate real estate and safety barriers such as what would be required to dispense hydrogen. What they have in common however is that for a station owner to invest and install station infrastructure, they must have the expectation of a reasonable return on their investment, if using their own capital or a low enough risk to justify the approval of a loan to build it. As an example, the Energy Information Administration estimates the levelized capital costs for natural gas in Annual Energy Outlook 2010[20]. This is an estimate of the capital cost recovery required, assuming that a 20-percent rate of return over a 5-year payback period would be sufficient to motivate investment in a standalone natural gas fueling station.

Assuming an initial cost of $2 million per station, the levelized capital cost of the station per gallon of diesel equivalent refueling capacity for station fuel throughput capacities of 1,250, 5,000, and 12,500 gallons per day would be $1.47, $0.37, and $0.15 respectively. The dramatic difference in capital cost per gallon demonstrates that throughput capacity (demand) is a driving consideration for decisions about investment in fueling stations. Too low a throughput would place an extraordinarily high capital cost on the price per gallon and make the fuel sale price out of reach of most consumers. Unfortunately, this is a 'chicken or the egg' problem. To achieve the high throughput to ensure a rapid payback period, there must be vehicles on the road capable of using the fuel.

This criterion considers the capital cost of the fueling station and the projected return on investment.

5.2 Commercial Readiness

The categories for the commercial readiness criteria in Table 2 represent a broad range of factors that all have some bearing on the commercialization of new vehicle technology. Descriptions of each criterion and their significance are provided below. Primarily, the criteria are established with the existing light- to medium-duty gasoline and diesel fleets as the baseline.

5.2.1 Vehicle Production and Support

This section addresses production and deployment of the vehicle and whether it is commercially viable.

5.2.1.1 Current vehicle production volume (Table 2, Criterion 7a)

According to the US DOT transportation statistics, there are approximately 240 million light duty vehicles on the road in the U.S. Sales figures indicate approximately 1.0-1.2 million cars and trucks are sold in the U.S. every month.

PASSENGER CARS	654,089
LIGHT TRUCKS	592,534
TOTAL LIGHT VEHICLE SALES, March 2011	1,246,623

	Mar 2011	% Chg from Mar'10	YTD 2011	% Chg from YTD 2010
Cars	**654,089**	**21.1**	1,532,710	**17.9**
Midsize	**320,251**	**19.1**	744,110	**17.2**
Small	**238,257**	**32.1**	552,457	**23.7**

Luxury	**87,123**	6.5	213,603	**8.6**
Large	**8,458**	-7.4	22,540	**3.7**
Light-duty trucks	**592,534**	12.7	1,527,095	**22.6**
Pickup	**157,514**	13.7	401,811	**23.1**
Cross-over	**247,644**	6.9	648,730	**19.0**
Minivan	**67,194**	12.6	170,108	**26.0**
Midsize SUV	**67,507**	42.5	169,683	**42.3**
Large SUV	**20,744**	-0.7	54,438	**7.7**
Small SUV	**18,182**	19.2	46,395	**27.6**
Luxury SUV	**13,749**	10.8	35,930	**10.6**
Total SUV/Cross-over	**367,826**	12.3	955,176	**21.9**
Total SUV	**120,182**	25.3	306,446	**28.4**
Total Cross-over	**247,644**	6.9	648,730	**19.0**

Source: Motor Intelligence, http://www.motorintelligence.com/m_frameset.html. Accessed April 2011.

5.2.1.2 Cumulative number of vehicles on the market – actual market impact (Table 2, Criterion 7b)

To achieve a significant market penetration may take several years. One example is the popular Toyota Prius Hybrid, sales of which just reached the 1 million mark in the U.S. in 2011. Even though it was the number one selling hybrid in the U.S. every year since its debut, it has taken eleven years of sales to reach that mark, which is still only 1/240th of the light duty population in the U.S. (0.42%). The Prius has gone through multiple spirals in its hybrid technology application since it was first introduced, but it remains the most recognized name in hybrid sedans. According to the news release from Toyota, 970,000 are still on the road which is higher than the average age of nine years for a light duty sedan. [21]

5.2.1.3 Vehicle maintenance and support infrastructure (Table 2, Criterion 7c)

If new maintenance support equipment or other infrastructure is required and once it has been designed and produced it must be distributed to the dealer or repair network. This would need to be done in sufficient quantities to support the roll-out of a new vehicle or technology upgrade. In addition to the equipment itself, sufficient training on the new technology should be accomplished for maintenance personnel so that they can be ready to support the system as soon as it is commercially available. Finally, spare parts in sufficient quantity should be distributed throughout the dealer network to ensure uninterrupted maintenance and repair processes.

5.2.2 Fueling Supply Chain

5.2.2.1 Fuel production capacity (Table 2, Criterion 8a)

This criterion evaluates whether there is sufficient capacity to produce enough fuel to service the vehicles on the market. With gasoline and diesel vehicles as a benchmark, there is currently 247 million vehicles on the road and highway vehicles consume 84% of all petroleum used in the U.S. (approximately 13 million barrels per day).[22]

5.2.2.2 Bulk fuel distribution infrastructure (Table 2, Criterion 8b)

This criterion considers if sufficient fueling distribution infrastructure exists to support bulk fuel distribution across the nation. As an example of scale, the U.S. petroleum distribution industry includes: 148 refineries, 38 Jones Act vessels, 3,300 coastal, Great Lakes and river tank barges, 200,000 rail tank cars, 1,400 petroleum product terminals, 100,000 tanker trucks, and approximately 200,000 miles of oil and refined product pipelines which are capable of delivering 138 billion gallons of fuel per year.[23]

5.2.2.3 Fuel delivery and handling safety (Table 2, Criterion 8c)

This criterion considers the general public safety as fuel is delivered around the country. The safest path is considered on-site generation and pipeline transportation as the general public does not come in contact with these modes of transportation. Rail transportation and barge are considered to have a lower safety rating, and finally over the road trucking is viewed as least safe due to the increased exposure to the public.

5.2.2.4 Vehicle fueling infrastructure distribution (Table 2, Criterion 8d)

This criterion considers if the fueling infrastructure (consumer fueling stations) exists sufficiently to support widespread deployment of mass-produced vehicles. There are currently 159,006 gasoline fueling stations across the country.[24] Is the fuel compatible with existing distribution or service station infrastructures and equipment.

5.3 Societal Improvement

The categories for the societal improvement criteria and the levels in the assessment matrix are different than the vehicle technology readiness and the commercial readiness matrices. The criteria in Table 3 represent the level of impact that the new technology may have on society.

- **Level 1: Low –** Technology has negative social impact compared to current benchmark.
- **Level 2: No Improvement / Criteria Met –** Technology can meet current benchmark.
- **Level 3: Moderate –** Social impact can be moderately improved over current benchmark.
- **Level 4: High –** Social impact can be significantly improved over current benchmark.

Descriptions of each criterion and their significance are provided below.

5.3.1 Vehicle EOL Environmental Impact

5.3.1.1 Vehicle End of Life distribution (Table 3, Criterion 9a)

This criterion is to consider the waste arising from end of life vehicles and to consider the percentage of the vehicle than can be reused or recycled. Currently, in the US, more than 75 percent of the average vehicle is recycled by weight.[25] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 required that 80 percent of the end-of-life vehicle by weight be reused or recycled by 2006, and it aims to increase the rate of material recovery in Europe to 85 percent by 2015. This data was used to set the criteria levels.

5.3.2 Fuel Impact

5.3.2.1 Local Air Quality / Tailpipe Emissions (Table 3, Criterion 10a)

Does the use of this new technology reduce the amount of tailpipe criteria pollutants from the vehicle as compared to similar vehicles in the class? Improvements in vehicle tailpipe emissions over existing technology have the potential to improve local air quality.

5.3.2.2 Petroleum use reduction (Table 3, Criterion 10b)

Oil is a finite resource and at some future date, the world oil production will reach a maximum, or peak, after which production will decline.[26] Oil peaking will create a severe fuel problem for the transportation sector. The U.S. petroleum consumption is 17,771,000 barrels per day with 84% used for transportation.[27] The problems associated with world oil production peaking will not be temporary, and therefore the issue deserves immediate attention. This criterion considers the petroleum portion of the fuel as a gasoline gallon equivalent.

5.3.2.3 Fuel renewability/resource depletion (Table 3, Criterion 10c)

There is a desire to replace a finite resource such as oil with a fuel that is more "renewable" to preserve our natural resources. A renewable fuel is defined by the U.S. Energy Policy Act of 2005[28] as a motor vehicle fuel that is produced from plant or animal products or wastes, as opposed to fossil fuel sources. Renewable fuels include ethanol, biodiesel and other motor vehicle fuels made from renewable sources. This criterion considers the renewable portion of the fuel as a gasoline gallon equivalent.

5.3.2.4 U.S. Energy independence (Table 3, Criterion 10d)

A major societal need is to insure the energy security of the United States. This criterion is a ratio of the amount of fuel that is produced from domestic sources to the total volume of fuel used normalized to a gallon of gasoline equivalent. (GGE) Gasoline is the current benchmark and the domestic fuel ratio is calculated using crude oil production and imports. The U.S. current refines 14.53 million barrels of crude oil per day, with only 5.61 million barrels per day of crude oil being from U.S. sources.[29] Monthly data on the origins of crude oil imports in December 2010 shows that the top five countries which accounted for 72 percent of U.S. oil imports were Canada (2,064 thousand barrels per day), Mexico (1,223 thousand barrels per day), Saudi Arabia (1,076 thousand barrels per day), Nigeria (1,024 thousand barrels per day), and Venezuela (825 thousand barrels per day). Total crude oil imports averaged 8,631 thousand barrels per day in December.[30]

Domestic crude oil production accounts for nearly 40 percent of the U.S. crude oil consumption. A second calculation used for this criteria considered all North American sources (U.S., Canada, and Mexico), which account for 61 percent of the U.S. crude oil use. Greater than 60 percent was therefore used as a second benchmark level.

5.3.2.5 Carbon Footprint (Table 3, Criterion 10e)

The life cycle emissions of CO2 (well-to-wheels) are the same or lower than other vehicles in each vehicle class (as determined by using modeling tools such as the Argonne National Laboratory GREET model.)

5.3.3 Cultural Impact

5.3.3.1 Change in driver behavior (Table 3, Criterion 11a)

Does ownership of this new technology vehicle significantly change driver behavior? This could include trip duration, cargo capacity, acceleration, average speed, or even commute distance.

Table 1: Technology Readiness

Criteria		U.S. DOT Light - Medium Duty Vehicle Technology Readiness						
		Bench testing			Production ready			
		1	2	3	4	5	6	7
		Unresolved (Concept) Technology has perceived benefit, but has not been shown to work for all required conditions.	**Low (Proof of Principle)** Mathematical models and separate lab experiments have demonstrated technology viability in all required conditions.	**Moderate (Demonstration / Validation)** Technology demonstration model has been built and successfully demonstrated requirements.	**High (Early Production)** Product can be sold into limited markets with some compromise in performance.	**Very High (Low Volume, Market Penetration)** Technology meets the needs of a specified market	**Criteria Met (High Volume, Market Acceptance)** Technology meets market needs	**Market Requirement Exceeded (Market Differentiator)**
Total Cost of Ownership								
1a	**Vehicle Cost competitiveness** (sticker price)	Technology breakthrough is required to make vehicle cost competitive	Vehicle is too expensive in low volumes. Cost models show vehicle can be competitive.	Vehicle price is only affordable through subsidies or lease.	Vehicle is a premium, but equivalent to the most expensive vehicle in class.	Vehicle is more expensive but has less than a 3 year life-cycle payback over gasoline	Vehicle initial purchase price is comparable with gasoline vehicle	Vehicle initial purchase price is 20% < than the current gasoline vehicle.
1b	**Fuel Economy / Cost per mile**	Technology breakthrough is required to make technology cost competitive	Cost models predict that fuel use can be cost competitive	2x market price with action plan to decrease	Cost is currently comparable with gasoline using government incentives and tax breaks.	Cost may be equivalent or a slight premium with no incentives or tax breaks required.	Cost per mile is cheaper than using current technology gasoline ICE	Cost per mile is <60% of the current technology gasoline ICE
1c	**Scheduled maintenance / service cost**	Long term maintenance plan has not been developed.	Reliability models have identified required maintenance which is projected to be cost comparable or better than the current benchmark	Vehicle maintenance plans have been documented and demonstrated on prototype vehicles.	Vehicle maintenance is a premium but is similar to a high performance vehicle.	Consumer is required to pay slight premium for routine maintenance (ex: synthetic oil)	Scheduled service cost is similar to current ICE technology.	Technology is more reliable than ICE and therefore maintenance cost >20% is reduced.

1d	**Unscheduled maintenance / repair cost / Warranty**	Technology breakthrough is required to make maintenance cost competitive	Reliability models demonstrate performance as good as or better than current benchmark	Durability and vehicle life demonstrated on over the road vehicles.	Unscheduled maintenance cost can be covered with a purchased limited warranty	Unscheduled maintenance cost is covered by 5yr / 50k mile warranty	Unscheduled maintenance cost is covered by 10yr / 100k mile warranty	Technology is more reliable than ICE. Lifetime powertrain warranty offered.
Vehicle Performance								
2a	**Single Fillup Maximum Trip Duration / time between fillups**	Extended trip range cannot be achieved without technology breakthrough.	Analysis shows that it is technically possible to achieve 400 mile range.	Technology breadboard has demonstrated 400 mile range. Prototype supports only a commuter one way trip. (>25 mile, twice a day)	Trip range is limited but it still meets consumers everyday trip range expectations (>50 mile) Fillup at home.	Trip range is limited but it still meets consumers everyday trip range expectations (>250 mile average work week)	Meets consumers extended trip range expectations (>400 miles, current benchmark)	Vehicle can reach 1000 mile trip range. (based on 12k miles per year, once a month fillup)
2b	**Continuous Operation Maximum Trip Duration** (continuous cross country road trip)	Extended trip range cannot be achieved without technology breakthrough.	Analysis shows that it is technically possible to achieve 24hr continuous operation.	Technology breadboard has demonstrated >24hr continuous operation.	Technology can run >8 hours (~400 miles) without requiring extended stop.	Technology can run >12 hours (~600 miles) without requiring extended stop.	Technology can run >24 hours (~1200 miles) without requiring extended stop.	Continuous operation not limited by technology
2c	**Clean air / Vehicle tailpipe emissions**	Technology breakthrough is required to meet emission requirements	Model of chemical process shows that emission standards will be met.	Widespread real world testing demonstrated emissions standards met.	Vehicle is certified to an EPA requirement greater than bin 5.	Meets EPA requirements but cannot be sold in all states.	Meets EPA LEV required standards and is certified for all states.	Significantly below the EPA requirements. ULEV, SULEV, ZLEV
2d	**Geographic operating restrictions**	Vehicle will likely not work in certain geographic areas without technology breakthrough.	Analysis shows that it is technically possible to achieve environmental requirements.	Demonstration vehicle specifically customized to work in each environment separately.	Vehicle works with some geographic technology limitations such as warm weather or low altitude	Vehicles will work in all locations with some minor adjustment to vehicle or fuel or performance loss.	Same geographic restrictions as gasoline. (operating temp. range, altitude, humidity, etc)	No geographic restrictions. (ex: does not require block heater in extreme cold climates)
Vehicle Usability								
3a	**Vehicle scheduled service interval (time in shop)**	Technology cannot be maintained to last the desired lifetime.	Reliability models demonstrate performance as good as or better than current benchmark	Trained technician required to constantly adjust performance.	Maximum once every two months plus an occasional breakdown.	Maximum once every two months	Maximum once every three months.	Less than twice a year.

3b	**Vehicle fueling operability / fill time**	No safe quick disconnect system has been identified	Takes 24 hrs to fill.	Average refueling time is significant and requires supervision and intervention. Rapid system however has been demonstrated.	Vehicle refueling time is significant but can be done in parallel with other activities (overnight, work, shopping, etc); Can be accomplished unsupervised.	Refueling process time is 2x the current vehicle fill time. (10 minutes maximum)	Fueling process is similar in skill and time as current gasoline. (<5 minutes)	Vehicle does not need to be refueled more than once a month.
3c	**Refueling system design stability**	No safe quick disconnect system has been identified	A refilling system has been demonstrated to withstand the outside environment and successfully refuel a vehicle.	Main OEMs have demonstrated separate technically capable refueling system designs however they have not standardized.	Fueling stations contain multiple connection systems to accommodate variation.	Universal connection with manual selection of fuel. (ex 110V, 220V, ethanol blender pump)	Vehicle refueling system is universal among all vehicle OEMs and is automatic with no intervention required from the customer	Refueling system uses only existing interface designs and technologies and does not require any development
Safety								
4a	**Vehicle operational Safety**	technology is only safe in a controlled test environment.	Design models and analysis demonstrate vehicle safety.	Can sell to limited markets; however cannot license vehicle for on-road usage	Vehicles can only be sold with limited performance and road access. (ex: speed and road type limited)	Vehicles can only be sold with limited performance. (ex: speed limited)	Vehicle can pass current vehicle crash standards and drive on all roads.	Vehicle has hazard avoidance system that puts vehicle into a safe mode during crash.
4b	**Fuel Operational Safety, Human Health (explosive, fire, breathing, skin contact)**	Technology will not pass safety requirements in its current form.	Technology safety has been demonstrated using specialty lab equipment	Can only be operated in a controlled area by trained professional.	Can only be operated by trained professional. Hazards identified. Safety features are inherent to equipment	Can be operated by trained consumer. Hazards identified. Safety features are inherent to equipment	Can be operated by average consumer with minimal training. Hazards identified. Safety features are inherent to equipment	Safe fuel defaults to a safe mode. No hazard
4c	**First responder safety**	Vehicle technology is not safe in an accident	Can only be operated on test tracks with specialized first responders present	Only limited use on public highways if first responders have been previously alerted/notified	Trained first responders must be specially requested to respond to an accident. (example: similar to HAZMAT)	Only a limited number of first responders are trained but are available in every area.	All first responders are trained and can deal with all mishaps	No special precautions must be taken by first responders
Vehicle Production Technology								

5a	**Vehicle production volume capacity / does it lend itself to mass production.**	Technology requires all hand assembly that will not meet production throughput	Vehicle design has been validated with a model to be appropriate for mass production.	Technology requires some hand assembly that cannot be automated	Some production tooling	All production tooling but low production rate.	Vehicles can be mass produced using available technology to meet demand. Full rate production.	Vehicles can be mass produced using existing tooling and technology with no further investment
5b	**Availability of critical materials for vehicle production**	Production cannot be supported by the known material resources.	Critical materials are available to produce full scale prototypes	Critical materials are available to produce up to 500 vehicles	Critical materials are available to produce 480 thousand vehicles.	Critical materials are available to produce >4.8 million vehicles.	Critical materials are available to produce >48 million vehicles.	No critical materials required for production.
5c	**Tech readiness of Vehicle Maintenance / Support Infrastructure**	Vehicle technology cannot be maintained with any known process.	Vehicle maintenance has been validated with a model to be appropriate for mass support.	Vehicles have been run to extended life. Vehicle maintenance has been successfully demonstrated.	Special tools / technologies are required to maintain vehicle, which only exist at designated maintenance providers.	Special tools / technologies are required to maintain vehicle, which are available to any maintenance provider.	Maintenance processes are well defined and documented. Required tools are commonly available to the general public.	No new maintenance and support infrastructure is required over and above existing vehicles.
Fueling Infrastructure Technology								
6a	**Long term fuel stability, storage, life**	Fuel degrades rapidly and cannot be stored.	Fuel can only be used in test equipment. Cannot be stored for resale. Has to be made and consumed real time.	Fuel storage has been demonstrated in a lab environment.	Fuel requires special storage for immediate sales	Fuel requires special storage and handling to meet life (1 year) requirements.	Fuel will not degrade for at least one year.	Fuel can be stored indefinitely, or generated on vehicle.
6b	**Station Technology / Infrastructure cost**	Significant cost reductions are required to make station cost effective to build.	Cost models predict that station installation costs can be recovered.	Station requires significant investment which can only be cost effective through incentives	Station installation costs can be recovered in <10 years.	Station installation costs can be recovered in <5 years.	Station modification costs can be recovered in <6 months.	Existing stations can be used with only minor equipment modifications

Table 2: Commercial Readiness

Criteria		U.S. DOT Light - Medium Duty Vehicle Commercial Readiness						
		Bench testing			Production ready			
		1	2	3	4	5	6	7
		Unresolved (Concept) Technology has perceived benefit, but has not been shown to work for all required conditions.	**Low (Proof of Principle)** Mathematical models and separate lab experiments have demonstrated technology viability in all required conditions.	**Moderate (Demonstration / Validation)** Technology demonstration model has been built and successfully demonstrated requirements.	**High (Early Production)** Product can be sold into limited markets with some compromise in performance.	**Very High (Low Volume, Market Penetration)** Technology can support at least a 2% market share.	**Criteria Met (High Volume, Market Acceptance)** Technology can support at least a 20% market share.	**Market Requirement Exceeded (Market Differentiator)**
Vehicle Production and Support								
7a	**Vehicle production volume**	No production line currently exists	Existing product line has been modified to demonstrate new build technology	Dedicated prototype build line exists for limited production volume.	> 20K vehicles per year being produced.	> 200K vehicles per year being produced.	> 2 million vehicles per year being produced.	Meets or exceeds the capacity of the "Big Three"
7b	**Cumulative # of vehicles on the market. Actual market impact.**	Only concept cars exist.	Full scale prototypes are being driven by designated drivers.	> 500 vehicles have been road tested by customers.	> 480 thousand vehicles on the road	> 4.8 million vehicles on the road.	> 48 million vehicles on the road.	> 240 million vehicles on the road.
7c	**Vehicle Maintenance / Support Infrastructure**	Vehicle repair and maintenance strategy has not been defined.	Component reliability and replacement parts have been identified through analysis (RCM, FMEA)	Support available at > one location.	Technical support is only available at regional repair centers.	Highly trained technicians available at dealerships for repairs.	Maintenance can be supported through the current infrastructure. No special garage requirements	Can be serviced by the operator.

Fueling Supply Chain								
8a	**Fuel production capacity / available energy within infrastructure**	Model shows that achieving the desired capacity is not possible with existing resources.	Capacity model shows that energy is available within infrastructure.	Limited to some dedicated fleets.	Limited commercial availability in some parts of the country	Feed stock available and fuel production has demonstrated capability for at least 3.6 billion gallons gasoline equivalent per year.	Feed stock available and fuel production has demonstrated capability for at least 36 billion gallons gasoline equivalent per year.	Excess capacity exists, site generation.
8b	**Bulk fuel distribution infrastructure**	No current infrastructure to distribute fuel.	Study of infrastructure requirements demonstrates possibility.	Limited fueling infrastructure set up around demonstration facilities.	Infrastructure capable of distributing 360 million gallons of gasoline equivalent per year.	Infrastructure capable of distributing 3.6 billion gallons of gasoline equivalent per year.	Infrastructure capable of distributing 36 billion gallons of gasoline equivalent per year.	Infrastructure capable of distributing in excess of 36 billion GGE
8c	**Fuel delivery and handling safety**	No current plan to enable fuel delivery.	Study of infrastructure requirements demonstrates that safety standards can be satisfied.	Bulk fuel can only be delivered to limited area.	Bulk fuel is delivered over road via trucking.	Bulk fuel is delivered "off-road" via rail and limited on-road trucking.	Bulk of fuel / energy is delivered "off-road" via pipeline or wires. May have limited on-road trucking.	Fuel can be generated on site or at home.
8d	**Vehicle fueling Infrastructure (range anxiety)**	No current plan to create fueling infrastructure	Study of infrastructure requirements demonstrates possibility	Demonstration stations functioning in representative climate locations across the country	Infrastructure in place for limited fuel distribution. Mainly limited fleet usage in local area only.	Fuel infrastructure is available in significant station density in high population cities.	Fuel is available in at least 16k-30k stations across the country.	Number of fueling stations meets or exceeds number of petroleum stations.

Table 3: Societal Improvement

Criteria		U.S. DOT Light - Medium Duty Vehicle Societal Impact			
		0	2	4	6
		✱	○	●	⬆
		Low Technology has negative social impact compared to current benchmark	**No Improvement / Criteria Met** Technology can meet current benchmark	**Moderate** Social impact can be moderately improved over current benchmark	**High** Social impact can be significantly improved over current benchmark.
2011 Vehicle					
9a	**Vehicle EOL Disposition**	Vehicle materials can be reused or recycled at <75%.	Vehicle materials can be reused or recycled at >75%.	Vehicle materials can be reused or recycled at >85%.	Vehicle materials can be reused or recycled at >95%.
fuel use (per GGE, gm/mi)					
10a	**Local Air Quality / Tailpipe Emissions (gm/mi criteria pollutants)**	Vehicle is rated > EPA LEV bin5.	Vehicle is rated ≤ EPA LEV bin5.	Vehicle is rated as ULEV.	Vehicle is rated as SULEV or ZLEV.
10b	**Petroleum use reduction**	Technology requires more than one gallon of petroleum to produce one GGE.	Technology requires less than one gallon of petroleum to produce one GGE.	Technology requires less than one half gallon of petroleum to produce one GGE.	Technology requires less than 10% of a gallon of petroleum to produce one GGE.
10c	**Fuel renewability / resource depletion**	Fuel sources are not renewable and are expected to be depleted within 50 yrs.	Fuel sources are not renewable but are expected to last more than 50 years.	> 50% of the fuel per gallon is made from renewable resources	> 90% of the fuel per gallon is made from renewable resources
10d	**Energy independence**	Supply of fuel / energy is limited and therefore negatively impacts transportation.	> 40% of the fuel per gallon is made from domestic resources	> 60% of the fuel per gallon is made from domestic resources	> 80% of the fuel per gallon is made from domestic resources
10e	**Carbon footprint**	Technology releases more carbon per GGE than gasoline.	Technology performs statistically similar to gasoline	Technology will reduce carbon emissions by >50% per GGE.	Technology will reduce carbon emissions by >90% per GGE.
Cultural Impact					
11a	**Change in driver behavior**	Requires behavior change with no improvement in driving experience.	Technology does not require any change in driving behavior	Change in driving behavior improves experience.	Technology makes driving accessible to more drivers and improves road safety.
	Other	Each fuel will have its own set of social and environmental impacts that may be unique to the fuel and comparing these issues is difficult. Petroleum spills can create catastrophic environmental damage (Gulf of Mexico, 2010), bioethanol can compete with food resources, fertilizer used to support biofuels may runoff and create dead zones, land reallocation may harm native species, nuclear waste, and land allocation for solar, and windmills have aesthetics issues and kill birds.			

6 Alternative Transportation Technology Readiness Summary

The following tables summarize the technology readiness for each vehicle and fuel technology studied and is intended as a quick visual comparison of each technology. Details for the rating of each criterion are in section 7 of this report. The ratings for the current state of technology readiness are based on the current state, or the "as-is, where-is" situation that we find at the end of our research program.

Readiness Metrics	ID	Readiness Criteria	E85	E20	Clean Diesel	B20
Technology Readiness						
Total Ownership Cost	1a	Vehicle Acquisition Cost	●	●	●	●
	1b	Fuel Economy-Cost Per Mile	○	●	⬆	●
	1c	Scheduled maintenance / service cost	●	●	●	●
	1d	Unscheduled maintenance / repair cost	●	●	●	●
Vehicle Performance	2a	Single Fill up Maximum Trip Duration	◉	●	⬆	●
	2b	Continuous Operation Maximum Trip Duration	●	●	●	●
	2c	Clean air / Vehicle tailpipe emissions	●	●	●	●
	2d	Geographic operating restrictions	●	●	●	●
Vehicle Usability	3a	Vehicle scheduled service interval	●	●	●	●
	3b	Vehicle fueling operability / fill time	●	●	●	●
	3c	Refueling system design stability	●	●	●	●
Safety	4a	Vehicle operational Safety	●	●	●	●
	4b	Fuel Operational Safety, Human Health	●	●	●	●
	4c	First responder safety	◉	●	●	●
Vehicle Production Technology	5a	Vehicle production volume capacity	●	●	●	●
	5b	Availability of critical materials for vehicle production	●	●	●	●
	5c	Vehicle Maintenance / Support Infrastructure	●	●	●	●
Commercial Readiness						
Fueling Infrastructure Technology	6a	Long term fuel stability, storage, life	◉	●	●	◉
	6b	Station Technology / Infrastructure cost	●	●	●	●
Vehicle Production and Support	7a	Current vehicle production volume	◉	●	●	●
	7b	Cumulative # of vehicles on the market.	◉	●	○	○
	7c	Vehicle Maintenance / Support Infrastructure	●	●	●	●
Fueling Supply Chain	8a	Fuel production capacity	◉	●	●	●
	8b	Bulk fuel distribution infrastructure	◉	●	●	●
	8c	Fuel delivery and handling safety	◉	●	●	●
	8d	Vehicle fueling Infrastructure (range anxiety)	○	●	●	●
Societal Improvement						
Vehicle EOL Environmental Impact	9a	Vehicle EOL Disposition	○	○	○	○
Fuel Impact	10a	Local Air Quality / Tailpipe Emissions	○	○	●	●
	10b	Petroleum use reduction	●	○	○	●
	10c	Fuel renewability / resource depletion	●	○	○	●
	10d	Energy independence	⬆	○	○	●
	10e	Carbon Footprint	○	○	●	⬆
Cultural Impact	11a	Change in driver behavior	○	○	●	●

Readiness Metrics	ID	Readiness Criteria	Hybrid Prius	PEV Leaf	PEV Volt
Technology Readiness					
Total Ownership Cost	1a	Vehicle Acquisition Cost	◉	○	○
	1b	Fuel Economy-Cost Per Mile	●	●	●
	1c	Scheduled maintenance / service cost	●	●	●
	1d	Unscheduled maintenance / repair cost	●	●	●
Vehicle Performance	2a	Single Fill up Maximum Trip Duration	●	◉	◉
	2b	Continuous Operation Maximum Trip Duration	●	○	⬆
	2c	Clean air / Vehicle tailpipe emissions	⬆	⬆	⬆
	2d	Geographic operating restrictions	◉	◉	◉
Vehicle Usability	3a	Vehicle scheduled service interval	●	⬆	⬆
	3b	Vehicle fueling operability / fill time	●	○	○
	3c	Refueling system design stability	●	◉	◉
Safety	4a	Vehicle operational Safety	●	●	●
	4b	Fuel Operational Safety, Human Health	●	●	●
	4c	First responder safety	●	◉	◉
Vehicle Production Technology	5a	Vehicle production volume capacity	●	◉	◉
	5b	Availability of critical materials for vehicle production	●	○	○
	5c	Vehicle Maintenance / Support Infrastructure	◉	◉	◉
Commercial Readiness					
Fueling Infrastructure Technology	6a	Long term fuel stability, storage, life	●	●	●
	6b	Station Technology / Infrastructure cost	●	◉	◉
Vehicle Production and Support	7a	Current vehicle production volume	◉	○	○
	7b	Cumulative # of vehicles on the market.	○	▣	▣
	7c	Vehicle Maintenance / Support Infrastructure	◉	◉	◉
Fueling Supply Chain	8a	Fuel production capacity	●	◉	●
	8b	Bulk fuel distribution infrastructure	●	●	●
	8c	Fuel delivery and handling safety	●	●	●
	8d	Vehicle fueling Infrastructure (range anxiety)	●	○	○
Societal Improvement					
Vehicle EOL Environmental Impact	9a	Vehicle EOL Disposition	○	○	○
Fuel Impact	10a	Local Air Quality / Tailpipe Emissions	●	⬆	●
	10b	Petroleum use reduction	●	⬆	●
	10c	Fuel renewability / resource depletion	●	⬆	●
	10d	Energy independence	●	⬆	●
	10e	Carbon Footprint	○	⬆	●
Cultural Impact	11a	Change in driver behavior	○	○	○

Readiness Metrics	ID	Readiness Criteria	H2 ICE	H2 Fuel Cell
Technology Readiness				
Total Ownership Cost	1a	Vehicle Acquisition Cost	□	✖
	1b	Fuel Economy-Cost Per Mile	□	✖
	1c	Scheduled maintenance / service cost	○	✱
	1d	Unscheduled maintenance / repair cost	○	✱
Vehicle Performance	2a	Single Fill up Maximum Trip Duration	○	●
	2b	Continuous Operation Maximum Trip Duration	●	◉
	2c	Clean air / Vehicle tailpipe emissions	⬆	◉
	2d	Geographic operating restrictions	○	⬆
Vehicle Usability	3a	Vehicle scheduled service interval	○	◉
	3b	Vehicle fueling operability / fill time	□	◉
	3c	Refueling system design stability	□	◉
Safety	4a	Vehicle operational Safety	◉	◉
	4b	Fuel Operational Safety, Human Health	○	○
	4c	First responder safety	●	●
Vehicle Production Technology	5a	Vehicle production volume capacity	◉	◉
	5b	Availability of critical materials for vehicle production	◉	◉
	5c	Vehicle Maintenance / Support Infrastructure	●	○
Commercial Readiness				
Fueling Infrastructure Technology	6a	Long term fuel stability, storage, life	⬆	⬆
	6b	Station Technology / Infrastructure cost	□	□
Vehicle Production and Support	7a	Current vehicle production volume	□	□
	7b	Cumulative # of vehicles on the market.	□	□
	7c	Vehicle Maintenance / Support Infrastructure	●	□
Fueling Supply Chain	8a	Fuel production capacity	□	□
	8b	Bulk fuel distribution infrastructure	□	□
	8c	Fuel delivery and handling safety	□	□
	8d	Vehicle fueling Infrastructure (range anxiety)	□	□
Societal Improvement				
Vehicle EOL Environmental Impact	9a	Vehicle EOL Disposition	○	□
Fuel Impact	10a	Local Air Quality / Tailpipe Emissions	⬆	⬆
	10b	Petroleum use reduction	⬆	⬆
	10c	Fuel renewability / resource depletion	⬆	⬆
	10d	Energy independence	⬆	⬆
	10e	Carbon Footprint	⬆	⬆
Cultural Impact	11a	Change in driver behavior	○	□

7 Fuels and Technologies Details

For each of the categories, we evaluated and rated the level of maturity based on specific data where it was available through published literature. Where it was not, we structured our research programs to collect that data in order to make informed judgments. For some technologies, such as fuel cells, development is in its early stages. However, we were able to make some judgments about hydrogen fuel based on our experiences with hydrogen ICE vehicles and fueling infrastructure, since some of the operational principles are the same. Each technology that we considered is included in its own subsection.

7.1 E85 Ethanol

E85 ethanol is a liquid fuel composed of up to 85% fuel ethanol (alcohol) and 15% unleaded gasoline. Currently this fuel is only compatible with so-called Flex Fuel Vehicles. E85 research conducted for this program is in Appendix B. The following table summarizes the rating for each criterion, and the supporting documentation and reasoning.

ID	Technology Readiness Criteria	E85 Rating 2011	E85 Research
1a	Vehicle Acquisition Cost	●	Flexible fuel vehicles (FFVs) are capable of operating on conventional gasoline, E85, or a mixture of both. Flexible fuel vehicles contain one fueling system, which is made up of ethanol compatible components and can adjust to accommodate a range of fuel properties from conventional gasoline to the higher oxygen content of E85.Flexible fuel vehicles are currently on the road and sell at the same vehicle acquisition cost as current conventional gasoline vehicles.[31]
1b	Fuel Economy-Cost Per Mile	○	E85 is currently available and the cost per mile driven is comparable to that of conventional gasoline; however, tax incentives are required.
1c	Scheduled maintenance / service cost	●	Scheduled maintenance and service cost is the same as conventional gasoline.
1d	Unscheduled maintenance / repair cost	●	Vehicle reliability and repair cost is the same as conventional gasoline.
2a	Single Fill up Maximum Trip Duration / time between fill ups	◉	E85 fuel has less energy per gallon than conventional gasoline therefore it requires more gallons per mile than conventional gasoline and therefore the trip duration is shorter on the same volume of fuel. Flexible fuel vehicles do contain a larger fuel tank than conventional gasoline vehicles of the same make and model to enable the vehicles to achieve reasonable trip durations between fill ups. However, FFV are unique in that they can fill up on E85, but also on conventional gasoline. The vehicle operator has the experience of a longer trip duration on conventional gasoline in the same vehicle as E85 so there will always be some range anxiety on E85, even if the E85 trip duration is the same as most conventional vehicles.
2b	Continuous Operation Maximum Trip Duration	●	There is no requirement on the vehicle or technology to mandate an extended break. Vehicle can run continuously for a 24 hour period.
2c	Clean air / Vehicle tailpipe emissions	●	Flexible fuel vehicles are currently certified to the EPA requirements on both gasoline and E85 fuel. Most emissions data shows a decrease in emissions when using E85; however, for this analysis, this difference is not considered to be significant because there is no change in vehicle certification to a tighter standard when using E85. (for example, running E85 does not change a FFV from a low emissions vehicle to an ultra low emissions vehicle)
2d	Geographic operating restrictions	●	Geographic operating restrictions for E85
3a	Vehicle scheduled service interval (scheduled time in shop)	●	Same as conventional vehicles

3b	Vehicle fueling operability / fill time	●	The fuelling time is similar to that of conventional gasoline and the fueling process requires no special skills by the operators.
3c	Refueling system design stability	●	Refueling of E85 has been designed to mimic conventional gasoline and the design is universal across all manufacturers.
4a	Vehicle operational Safety	●	Flexible fuel vehicles meet the required safety standards and can operate on all roads without restrictions.
4b	Fuel Operational Safety, Human Health	●	Fuel operation, storage and safety are well documented for E85, and are covered in the American Petroleum Institute publication 1626. This publication addresses ethanol and ethanol fuel characteristics, gasoline-ethanol blending techniques, compatibility of materials, filling station conversion, approaches to respond to releases and spills, tank truck and rail car loading and transportation issues, fuel quality issues, and fire protection.[32]
4c	First responder safety	◉	E85 fires can only be extinguished with alcohol resistant (AR type) foams (AR-AFFF & AR-FFFP). All other types of foams or water additives typically used to extinguish gasoline fires are ineffective as the foam blanket is destroyed when it strikes the fuel surface.[33] The Ethanol Emergency Response Coalition (EERC) was formed to address safety concerns with the transport and handling of renewable fuels. Additional nationwide first responder training is required.
5a	Vehicle production volume capacity	●	Flexible fuel vehicles are similar in design to conventional gasoline vehicles and can be (and are being) produced on the same high volume manufacturing lines.
5b	Availability of critical materials for vehicle production	●	Same as conventional gasoline vehicles.
5c	Tech readiness of Vehicle Maintenance / Support Infrastructure	●	Same as conventional gasoline vehicles.
ID	**Commercial Readiness Criteria**	**E85 Rating 2011**	**E85 Research**
6a	Long term fuel stability, storage, life	◉	Ethanol by itself has no issues with long term storage and is very stable; however, it has an affinity for water which will cause phase separation with the gasoline component of E85.
6b	Station Technology / Infrastructure cost	●	NREL conducted a survey on the costs incurred on 120 E85 stations—84 new tank installations and 36 existing tank conversions. The median price for a new tank installation was $59,153 and the median price for a conversion of an existing tank was $11,237.[34] E85 station infrastructure cost is therefore considered to be recoverable with a reasonable fuel sales volume.
7a	Current vehicle production volume	◉	Flexible fueled vehicles production in 2008 and 2009 was just over 1 million vehicles per year for the U.S. market. The three largest U.S. automakers—General Motors Co., Ford Motor Co. and Chrysler—have already agreed to make half of their annual vehicle production flex-fuel capable beginning in 2012.[35] [36]
7b	Cumulative # of vehicles on the market. Actual market impact.	◉	There is an estimated 8.4 million flexible fuel vehicles currently on the road in the U.S.[37] representing about a 3.5 percent market share.
7c	Vehicle Maintenance / Support Infrastructure	●	Same as conventional gasoline vehicles.
8a	Fuel production capacity / available energy within infrastructure	◉	The 2010 U.S. ethanol production was 13.2 billion gallons.[38]
8b	Bulk fuel distribution infrastructure	◉	According to the USDA, most ethanol is currently produced in the Nation's heartland, but 80 percent of the U.S. population lives along the coastlines. In 2005, rail was the primary transportation mode for ethanol, shipping 60 percent of the ethanol production, trucks shipped 30 percent and barges 10 percent.[39] An order of magnitude increase in transportation needs will require bulk fuel distribution such as a dedicated pipeline to move fuel from the

			heartland to the coasts.
8c	Fuel delivery and handling safety	◉	Same as 8b
8d	Vehicle fueling Infrastructure	○	At the time of this paper, there are currently 2,345 E85 fueling stations in the U.S.; however, most are concentrated around the fuel production in the country's mid-west, not around the population centers.[40]
ID	**Societal Improvement Readiness Criteria**	**E85 Rating 2011**	**E85 Research**
9a	Vehicle EOL Disposition	○	Flexible fuel vehicles are essentially conventional gasoline vehicles. Conventional vehicles and vehicle components can be reused and recycled at ~75% in the current U.S. infrastructure.
10a	Local Air Quality / Tailpipe Emissions	○	Research has shown that tailpipe emissions from E85 sources are generally less than those of gasoline; however, the benefit is not significant enough to change the vehicle rating to that of an ultra low emissions vehicle.[41] Other research has concluded that E85 is unlikely to improve air quality over future gasoline vehicles.[42] Flex fuel vehicles are rated <Bin5.
10b	Petroleum use reduction	●	> 50% reduction is petroleum use.
10c	Fuel renewability / resource depletion	●	> 50% is from renewable ethanol
10d	Energy independence	⬆	E85 contains an average ethanol content of 80%, which is all produced domestically. The remaining 20% is petroleum, which is 60% domestic; therefore, 92% of E85 is from domestic sources.
10e	Carbon footprint	○	Researchers at Argonne National Laboratory found that life cycle GHG emissions from corn-based E85 are 17% to 23% below those of regular gasoline on a per-mile basis.[43]
11a	Change in driver behavior	○	There is no driving behavioral difference between FFV and conventional gasoline vehicle.

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7.2 E20 Ethanol

E20 ethanol is a liquid fuel composed of up to 20% fuel ethanol and 80% unleaded gasoline. This fuel is intended for use in all engines that currently operate on E10 fuel. Currently this fuel has only been approved with Flex Fuel Vehicles, but some research has shown compatibility with conventional gasoline vehicles. E20 research conducted for this program is in Appendix B. The following table summarizes the rating for each criterion, and the supporting documentation and reasoning.

ID	Technology Readiness Criteria	E20 Rating 2011	E20 Research
1a	Vehicle Acquisition Cost	●	Same as conventional gasoline vehicles.
1b	Fuel Economy-Cost Per Mile	●	Same as conventional gasoline vehicles. Research at RIT has shown that the cost per mile on E20 is similar to the cost per mile running on conventional gasoline.
1c	Scheduled maintenance / service cost	●	Same as conventional gasoline vehicles. Research at RIT has shown that there is no additional maintenance cost while running E20 over the cost to run conventional gasoline.
1d	Unscheduled maintenance / repair cost	●	Same as conventional gasoline vehicles. Research at RIT has shown that there is no additional maintenance cost while running E20 over the cost to run conventional gasoline.
2a	Single Fill up Maximum Trip Duration / time between fill ups	●	Same as conventional gasoline vehicles. Research at RIT has shown that the fuel economy is reduced by 6% which in turn reduces the maximum trip duration by 6%. This difference is not perceived as a significant change.
2b	Continuous Operation Maximum Trip Duration	●	Same as conventional gasoline vehicles.
2c	Clean air / Vehicle tailpipe emissions	●	Same as conventional gasoline vehicles. Research at RIT has shown that conventional vehicles running on E20 still meet the EPA requirements.
2d	Geographic operating restrictions	●	Same as conventional gasoline vehicles.
3a	Vehicle scheduled service interval (scheduled time in shop)	●	Same as conventional gasoline vehicles.
3b	Vehicle fueling operability / fill time	●	Same as conventional gasoline vehicles.
3c	Refueling system design stability	●	Same as conventional gasoline vehicles.
4a	Vehicle operational Safety	●	Same as conventional gasoline vehicles.
4b	Fuel Operational Safety, Human Health	●	Same as conventional gasoline vehicles.
4c	First responder safety	●	Same as conventional gasoline vehicles.
5a	Vehicle production volume capacity	●	Same as conventional gasoline vehicles.
5b	Availability of critical materials for vehicle production	●	Same as conventional gasoline vehicles.
5c	Tech readiness of Vehicle Maintenance / Support Infrastructure	●	Same as conventional gasoline vehicles.

ID	Commercial Readiness Criteria	E20 Rating 2011	E20 Research
6a	Long term fuel stability, storage, life	●	Same as conventional gasoline vehicles.
6b	Station Technology / Infrastructure cost	●	Same as conventional gasoline vehicles.
7a	Current vehicle production volume	●	Same as conventional gasoline vehicles.
7b	Cumulative # of vehicles on the market. Actual market impact.	●	Same as conventional gasoline vehicles.
7c	Vehicle Maintenance / Support Infrastructure	●	Same as conventional gasoline vehicles.
8a	Fuel production capacity / available energy within infrastructure	●	Same as conventional gasoline vehicles.
8b	Bulk fuel distribution infrastructure	●	Same as conventional gasoline vehicles.
8c	Fuel delivery and handling safety	●	Same as conventional gasoline vehicles.
8d	Vehicle fueling Infrastructure	●	Same as conventional gasoline vehicles.

ID	Societal Improvement Readiness Criteria	E20 Rating 2011	E20 Research
9a	Vehicle EOL Disposition	○	No change in societal benefit. Same as conventional gasoline vehicles.
10a	Local Air Quality / Tailpipe Emissions	○	No change in societal benefit. Same as conventional gasoline vehicles.
10b	Petroleum use reduction	○	No change in societal benefit. Minimal improvement over conventional gasoline vehicles with ethanol produced from corn.
10c	Fuel renewability / resource depletion	○	No change in societal benefit. Minimal improvement over conventional gasoline vehicles.
10d	Energy independence	○	Slight improvement in societal benefit. 20% ethanol assumed to be domestic; however, only 40% of the remaining 80% petroleum assumed to be domestic.
10e	Carbon footprint	○	No change in societal benefit. Same as conventional gasoline vehicles.
11a	Change in driver behavior	○	No change in societal benefit. Same as conventional gasoline vehicles.

7.3 Clean Diesel

Clean diesel includes advanced technology to reduce emissions from compression ignition/diesel engines. Diesel research conducted for this program is in Appendix C. The following table summarizes the rating for each criterion, and the supporting documentation and reasoning.

ID	Technology Readiness Criteria	CD Rating 2011	Clean Diesel Research
1a	Vehicle Acquisition Cost	●	Clean diesel vehicles are in production from several manufacturers and on the road. Price is roughly equivalent to other vehicles in the class. Federal tax credits have been offered for purchase of clean diesel vehicles.
1b	Fuel Economy-Cost Per Mile	⬆	New technology diesel sedans (Volkswagen, Audi) have demonstrated fuel economy in excess of 40 mpg. But diesel fuel prices historically are slightly higher than gasoline per gallon according to US Energy Information Administration (http://www.eia.doe.gov/oog/info/gdu/gasdiesel.asp)
1c	Scheduled maintenance / service cost	●	Same as conventional gasoline vehicles.
1d	Unscheduled maintenance / repair cost	●	Same as conventional gasoline vehicles.
2a	Single Fill up Maximum Trip Duration / time between fill ups	⬆	With increased fuel mileage, current range exceeds that of conventional gasoline vehicles.
2b	Continuous Operation Maximum Trip Duration	●	Same as conventional gasoline vehicles.
2c	Clean air / Vehicle tailpipe emissions	●	Same or better than conventional gasoline vehicles. Meets all EPA standards.
2d	Geographic operating restrictions	●	Same as conventional gasoline vehicles.
3a	Vehicle scheduled service interval (scheduled time in shop)	●	Same as conventional gasoline vehicles.
3b	Vehicle fueling operability / fill time	●	Same as conventional gasoline vehicles.
3c	Refueling system design stability	●	Same as conventional gasoline vehicles.
4a	Vehicle operational Safety	●	Same as conventional gasoline vehicles.
4b	Fuel Operational Safety, Human Health	●	Same as conventional diesel vehicles.
4c	First responder safety	●	Same as conventional gasoline vehicles.
5a	Vehicle production volume capacity	●	Same as conventional diesel.
5b	Availability of critical materials for vehicle production	●	Same as conventional gasoline vehicles.
5c	Tech readiness of Vehicle Maintenance / Support Infrastructure	●	Same as conventional gasoline or diesel vehicles.
ID	**Commercial Readiness Criteria**	**CD Rating 2011**	**Clean Diesel Research**
6a	Long term fuel stability, storage, life	●	Uses conventional ULSD or biodiesel.

6b	Station Technology / Infrastructure cost	●	Uses conventional ULSD or biodiesel.
7a	Current vehicle production volume	●	Same as conventional gasoline vehicles.
7b	Cumulative # of vehicles on the market. Actual market impact.	○	Clean diesel vehicles (primarily from European manufacturers) have been offered for sale in the U.S. for about three years.
7c	Vehicle Maintenance / Support Infrastructure	●	Same as conventional gasoline vehicles.
8a	Fuel production capacity / available energy within infrastructure	●	Uses conventional ULSD or biodiesel.
8b	Bulk fuel distribution infrastructure	●	Uses conventional ULSD or biodiesel.
8c	Fuel delivery and handling safety	●	Uses conventional ULSD or biodiesel.
8d	Vehicle fueling Infrastructure	●	Uses conventional ULSD or biodiesel.
ID	**Societal Improvement Readiness Criteria**	**CD Rating 2011**	**Clean Diesel Research**
9a	Vehicle EOL Disposition	○	Same as conventional gasoline vehicles.
10a	Local Air Quality / Tailpipe Emissions	●	Fueleconomy.gov rates clean diesel vehicles slightly higher than conventional gasoline for GHG emissions.
10b	Petroleum use reduction	○	Uses conventional ULSD or biodiesel.
10c	Fuel renewability / resource depletion	○	Uses conventional ULSD or biodiesel.
10d	Energy independence	○	Uses conventional ULSD or biodiesel.
10e	Carbon footprint	●	Reduced carbon footprint due to increased fuel economy.
11a	Change in driver behavior	●	With increased fuel mileage, current range exceeds that of conventional gasoline vehicles. Allows for wider choices in fueling location s to obtain best price.

7.4 B20 Biodiesel with Clean Diesel Vehicle

B20 biodiesel is a liquid fuel composed of up to 20% biodiesel fuel and 80% conventional Ultra Low Sulfur Diesel. The feedstock for the biodiesel may originate from multiple sources such as agricultural products or waste grease. Clean diesel includes advanced technology to reduce emissions from compression ignition/diesel engines. Diesel research conducted for this program is in Appendix C. The following table summarizes the rating for each criterion, and the supporting documentation and reasoning.

ID	**Technology Readiness Criteria**	**B20 Rating 2011**	**B20 Biodiesel with Clean Diesel Research**
1a	Vehicle Acquisition Cost	●	No change to ULSD Clean Diesel vehicle required.
1b	Fuel Economy-Cost Per Mile	●	The added cost and efficiency penalty of B20 makes the cost equivalent to conventional gasoline vehicles.
1c	Scheduled maintenance / service cost	●	Same as conventional gasoline vehicles
1d	Unscheduled maintenance / repair cost	●	Same as conventional gasoline vehicles.
2a	Single Fill up Maximum Trip Duration / time between fill ups	⬆	Better than conventional gasoline vehicles.
2b	Continuous Operation Maximum Trip Duration	⬆	Better than conventional gasoline vehicles
2c	Clean air / Vehicle tailpipe emissions	⬆	Reduced CO and Soot levels
2d	Geographic operating restrictions	●	Mixtures of 20% biodiesel, 30% ULSD and 50% kerosene have been resistant to cold weather gelling.
3a	Vehicle scheduled service interval (scheduled time in shop)	●	Same as conventional gasoline vehicles.
3b	Vehicle fueling operability / fill time	●	Same as conventional gasoline vehicles.
3c	Refueling system design stability	●	Same as conventional gasoline vehicles.
4a	Vehicle operational Safety	●	Same as conventional gasoline vehicles.
4b	Fuel Operational Safety, Human Health	●	Same as conventional gasoline vehicles.
4c	First responder safety	●	Lower flash point than gasoline, but still flammable.
5a	Vehicle production volume capacity	●	Worldwide, similar to gasoline vehicles
5b	Availability of critical materials for vehicle production	●	Same as gasoline vehicle.
5c	Tech readiness of Vehicle Maintenance / Support Infrastructure	●	Same as gasoline vehicle.
ID	**Commercial Readiness Criteria**	**B20 Rating 2011**	**B20 Research**
6a	Long term fuel stability, storage, life	○	Biodiesel shelf life is typically between 6 months and 1 year.

6b	Station Technology / Infrastructure cost	●	Same as conventional gasoline vehicles.
7a	Current vehicle production volume	●	Greater than 200K vehicles produced annually.
7b	Cumulative # of vehicles on the market. Actual market impact.	○	Clean diesel vehicles (primarily from European manufacturers) have been offered for sale in the U.S. for about three years.
7c	Vehicle Maintenance / Support Infrastructure	●	Same as conventional gasoline vehicles.
8a	Fuel production capacity / available energy within infrastructure	○	Limited availability in some parts of the country.
8b	Bulk fuel distribution infrastructure	●	Same as conventional gasoline vehicles.
8c	Fuel delivery and handling safety	●	Same as conventional gasoline vehicles.
8d	Vehicle fueling Infrastructure	●	Same as conventional gasoline vehicles.
ID	**Societal Improvement Readiness Criteria**	**B20 Rating 2011**	**B20 Research**
9a	Vehicle EOL Disposition	○	Same as conventional gasoline vehicles.
10a	Local Air Quality / Tailpipe Emissions	●	Per RIT study, B25 reduced CO by 10% and soot by 35%. Some emissions are produced during planting and harvesting crops.
10b	Petroleum use reduction	○	20% reduction in ULSD from mix. Some ULSD may be consumed during planting and harvesting crops.
10c	Fuel renewability / resource depletion	○	Similar to conventional gasoline vehicles.
10d	Energy independence	○	Similar to conventional gasoline vehicles.
10e	Carbon footprint	●	Similar to conventional gasoline vehicles.
11a	Change in driver behavior	●	Same as conventional gasoline vehicles.

7.5 Hybrid Gasoline-Electric Vehicles

A hybrid gasoline and electric vehicle uses a combination of conventional gasoline engine and electric assist. The current most popular model is the Toyota Prius. The following table summarizes the rating for each criterion, and the supporting documentation and reasoning.

ID	Technology Readiness Criteria	Hybrid Rating 2011	Hybrid Research
1a	Vehicle Acquisition Cost	◉	There is currently a premium to purchase a hybrid vehicle over the conventional gasoline counterpart; however, the payback period for some models is less than three years.[44 45 46]
1b	Fuel Economy-Cost Per Mile	●	The hybrid technology is specifically designed to reduce gasoline consumption and therefore increase the fuel economy.
1c	Scheduled maintenance / service cost	●	Honda claims that the service costs for the Honda Civic Hybrid will not be higher than a conventional gasoline vehicle. “The service interval is the same as any other Honda car, with the first service at 1,000km followed by 10,000km, 20,000km and so on. No additional servicing is required on the Honda Civic Hybrid.”[47]
1d	Unscheduled maintenance / repair cost	●	Hybrid technology can be reliable and covered by manufacturer’s warranty. As an example, the Toyota hybrid warranty is the same as the conventional gasoline vehicle warranty, with the addition of 8 year, 100,000 mile warranty coverage on hybrid related components.[48]
2a	Single Fill up Maximum Trip Duration / time between fill ups	●	Same as conventional vehicle. Fuel economy greater than conventional vehicle; however, sometimes the tank is reduced to make room for additional hybrid equipment.
2b	Continuous Operation Maximum Trip Duration	●	Same as conventional gasoline vehicle.
2c	Clean air / Vehicle tailpipe emissions	⬆	Hybrid vehicles such as the Toyota Prius and the Honda Civic have cleaner emissions that conventional gasoline vehicle as demonstrated by their rating as Advanced Technology Partial Zero Emission Vehicles (AT-PZEV).
2d	Geographic operating restrictions	◉	There is significant variation in performance of batteries as a function of temperature. At about zero degrees Fahrenheit, both Li-ion and NiMH batteries have almost none of their power available. Thus, until a battery is warmed up, it will not provide rated power. Vehicle manufactures have designed systems such as battery warmers to help with this problem; however, combination of the added energy use and the cold temperature reduces the performance of the vehicle.[49]
3a	Vehicle scheduled service interval (scheduled time in shop)	●	Same as conventional gasoline vehicle.
3b	Vehicle fueling operability / fill time	●	Same as conventional gasoline vehicles.
3c	Refueling system design stability	●	Same as conventional gasoline vehicles.
4a	Vehicle operational Safety	●	Many hybrid vehicles are able to achieve five star crash ratings.[50 51]
4b	Fuel Operational Safety, Human Health	●	Same as conventional gasoline vehicles.
4c	First responder safety	●	Training is in place to assist first responders in case of an accident with a hybrid vehicle.[52 53]
5a	Vehicle production volume capacity	●	Hybrid vehicles are currently being mass produced. Production equipment exists.
5b	Availability of critical materials for vehicle production	●	There are no shortages of critical materials to produce hybrid vehicles in current production volumes.

5c	Tech readiness of Vehicle Maintenance / Support Infrastructure	●	Hybrid vehicles have been on the commercial market for several years and the maintenance and support equipment has been defined and produced.
ID	**Commercial Readiness Criteria**	**Hybrid Rating 2011**	**Hybrid Research**
6a	Long term fuel stability, storage, life	●	Same as conventional gasoline vehicles.
6b	Station Technology / Infrastructure cost	●	Same as conventional gasoline vehicles.
7a	Current vehicle production volume	◉	274,210 Hybrid Electric Vehicles were produced in 2010.[54]
7b	Cumulative # of vehicles on the market. Actual market impact.	○	Approximately 1.9 million vehicles have been sold since 1999. [55]
7c	Vehicle Maintenance / Support Infrastructure	●	Hybrid vehicles have been offered on the commercial market by major automakers for several years and the maintenance and support structure is in place.
8a	Fuel production capacity / available energy within infrastructure	●	Same as conventional gasoline vehicles.
8b	Bulk fuel distribution infrastructure	●	Same as conventional gasoline vehicles.
8c	Fuel delivery and handling safety	●	Same as conventional gasoline vehicles.
8d	Vehicle fueling Infrastructure	●	Same as conventional gasoline vehicles.
ID	**Societal Improvement Readiness Criteria**	**Hybrid Rating 2011**	**Hybrid Research**
9a	Vehicle EOL Disposition	●	Same as conventional gasoline vehicles
10a	Local Air Quality / Tailpipe Emissions	●	Moderate reduction in emissions due to reduced fuel usage.
10b	Petroleum use reduction	●	Moderate reduction in petroleum usage due to increased fuel economy
10c	Fuel renewability / resource depletion	●	Moderate reduction in resource depletion due to reduced petroleum usage. Other resource impacts (battery materials) are still TBD.
10d	Energy independence	●	Moderate increase in independence due to reduced petroleum usage. Could be offset if strategic materials for batteries become scarce.
10e	Carbon footprint	○	Hybrid technology can reduce the well-to-wheel greenhouse gas emissions by 35%. [56]
11a	Change in driver behavior	○	Driver experience remains essentially unchanged.

7.6 Plug-in Electric Vehicles

A plug-In electric vehicle runs exclusively on electric power which is supplied by off-board sources. A current representative model is the Nissan Leaf. The following table summarizes the rating for each criterion, and the supporting documentation and reasoning.

ID	Technology Readiness Criteria	Plug-in Rating 2011	Plug-in Electric Research
1a	Vehicle Acquisition Cost	○	MSRP of a new Nissan Leaf is $35-$37,000.
1b	Fuel Economy-Cost Per Mile	●	All electric, no liquid fuels required.
1c	Scheduled maintenance / service cost	●	No oil changes required.
1d	Unscheduled maintenance / repair cost	●	Battery warranty is 96 months/100K miles. Other normal warranties for rest of vehicle
2a	Single Fill up Maximum Trip Duration / time between fill ups	◉	100 miles according to EPA LA4 driving cycle. EPA rated at 73 miles.
2b	Continuous Operation Maximum Trip Duration	○	With a trickle charge cable, can be recharged in 10 hours. With a 220V system, time is reduced to 3.5 hours.
2c	Clean air / Vehicle tailpipe emissions	⬆	Zero Emissions Vehicle (ZEV).
2d	Geographic operating restrictions	◉	None currently published by Nissan
3a	Vehicle scheduled service interval (scheduled time in shop)	⬆	No oil changes required. No other regular maintenance on electric system.
3b	Vehicle fueling operability / fill time	○	With a trickle charge cable, can be recharged in 10 hours. With a 220V system, time is reduced to 3.5 hours.
3c	Refueling system design stability	◉	SAE J1772 standard connector for Level 2 charging.
4a	Vehicle operational Safety	●	5 Star Crash rating.
4b	Fuel Operational Safety, Human Health	●	Electricity is only fuel. Normal precautions apply. Charging system has several fail safe modes.
4c	First responder safety	◉	Similar to hybrid vehicles
5a	Vehicle production volume capacity	◉	Nissan is building a dedicated Leaf production facility in Tennessee. Production volume is estimated to be capable of 150,000 vehicles per year.
5b	Availability of critical materials for vehicle production	○	At present sufficient, but competing with hybrid vehicles for battery materials.
5c	Tech readiness of Vehicle Maintenance / Support Infrastructure	◉	Vehicle offered for sale, dealer network is available for support.
ID	**Commercial Readiness Criteria**	**Plug-in Rating 2011**	**Plug-in Electric Research**
6a	Long term fuel stability, storage, life	●	Electricity has no storage issues.
6b	Station Technology / Infrastructure cost	◉	Charging stations are relatively inexpensive and are provided with the vehicle purchase.
7a	Current vehicle production volume	○	Current production volumes are approximately 1000 vehicles per month.

7b	Cumulative # of vehicles on the market. Actual market impact.	▣	Current production sales are approximately 1000 vehicles per month in 2011. Actual market impact is <50K vehicles.
7c	Vehicle Maintenance / Support Infrastructure	◉	Support infrastructure is available at dealers or not required due to electric motor operation.
8a	Fuel production capacity / available energy within infrastructure	◉	Electric grid capacity sufficient to handle production volume at this time.
8b	Bulk fuel distribution infrastructure	●	Electricity universally available. Only dedicated charging station required.
8c	Fuel delivery and handling safety	●	Electricity is a known substance and universally available. Charging stations are provided with numerous safety features.
8d	Vehicle fueling Infrastructure	○	Charging stations available in limited area only or at owner residences.
ID	**Societal Improvement Readiness Criteria**	**Plug-in Rating 2011**	**Plug-in Electric Research**
9a	Vehicle EOL Disposition	○	Batteries can be recycled, but the extent is undetermined at this point. The rest of the vehicle is identical to gasoline vehicles.
10a	Local Air Quality / Tailpipe Emissions	⬆	No tailpipe emissions
10b	Petroleum use reduction	⬆	Significant reduction in petroleum to operate, however upstream impacts of electricity generation need to be addressed.
10c	Fuel renewability / resource depletion	⬆	Electricity is 100% renewable.
10d	Energy independence	⬆	Electricity production is primarily domestic.
10e	Carbon footprint	⬆	Significant reductions possible, however, upstream impacts of electricity generation need to be addressed.
11a	Change in driver behavior	○	Some change in driver behavior to accomplish charging actions. Adjustments required for location of charging stations.

7.7 Plug-in Electric with Gasoline Range Extension Vehicles

A plug-In electric vehicle with gasoline range extension runs exclusively on electric power; however is also contains a generator that runs on conventional fuel to extend the range of the vehicle. A current representative model is the Chevy Volt. The following table summarizes the rating for each criterion, and the supporting documentation and reasoning.

ID	Technology Readiness Criteria	PEV with gas Rating 2011	Plug-in Electric with Gasoline Range Extension Research
1a	Vehicle Acquisition Cost		MSRP for a 2012 Volt is $39,145. Significantly higher than vehicles in the class – mid sized sedan.
1b	Fuel Economy-Cost Per Mile		EPA MPG Equivalent - City (Electric): 95 EPA MPG Equivalent - Hwy (Electric): 93 EPA Est. Fuel Economy City (Gas): 35 MPG EPA Est. Fuel Economy Highway (Gas): 40 MPG Chevy predicts $1.50 per day cost of electricity If driving 35 miles or less.
1c	Scheduled maintenance / service cost		Gasoline engine still requires periodic service, though less than conventional vehicles if operation is primarily on batteries.
1d	Unscheduled maintenance / repair cost		Bumper-to-Bumper Limited Warranty: 3 Years/36,000 miles Powertrain/Drivetrain limited warranty: 5 Years/100,000 miles Battery and Voltec component limited warranty: 8 years/100,000 miles
2a	Single Fill up Maximum Trip Duration / time between fill ups		Battery Range (Electric): 35 mi Cruising Range - City (Gas): 325.50 mi Cruising Range - Hwy (Gas): 372.00 mi Total Range: 407.00 mi
2b	Continuous Operation Maximum Trip Duration		No restrictions
2c	Clean air / Vehicle tailpipe emissions		Overall lower emissions. Significantly lower when operating on battery alone.
2d	Geographic operating restrictions		None identified by OEM
3a	Vehicle scheduled service interval (scheduled time in shop)		Still TBD but promises to be better than gasoline vehicles if using primarily electric motor operation.
3b	Vehicle fueling operability / fill time		At 110V, charging time is 10 hours, with 240V system, time is reduced to 4 hours.

3c	Refueling system design stability	◉	SAE J1772 standard connector for Level 2 charging.
4a	Vehicle operational Safety	●	Questions remain about Volt battery safety. [57]
4b	Fuel Operational Safety, Human Health	●	Questions remain about Volt battery safety. (ibid)
4c	First responder safety	◉	Questions remain about Volt battery safety. (ibid)
5a	Vehicle production volume capacity	◉	GM forecasts a production capacity of 60K vehicles per year.[58]
5b	Availability of critical materials for vehicle production	○	At present sufficient, but competing with hybrid vehicles for battery materials.
5c	Tech readiness of Vehicle Maintenance / Support Infrastructure	◉	Support infrastructure is available at dealers or not required due to electric motor operation.
ID	**Commercial Readiness Criteria**	**PEV with gas Rating 2011**	**Plug-in Electric with Gasoline Range Extension Research**
6a	Long term fuel stability, storage, life	●	Electricity has no storage issues. Gasoline is a backup fuel.
6b	Station Technology / Infrastructure cost	◉	Charging stations are relatively inexpensive and are provided with the vehicle purchase. Gasoline is a backup fuel.
7a	Current vehicle production volume	○	Current GM production is approximately 2300 vehicles per month. (ibid)
7b	Cumulative # of vehicles on the market. Actual market impact.	▣	Number of Volts produced is approximately 10,000, with 5,000 on the road. (ibid).
7c	Vehicle Maintenance / Support Infrastructure	◉	Support infrastructure is available at dealers or not required due to electric motor operation.
8a	Fuel production capacity / available energy within infrastructure	●	Electric grid capacity sufficient to handle production volume at this time.
8b	Bulk fuel distribution infrastructure	●	Electricity universally available. Only dedicated charging station required.
8c	Fuel delivery and handling safety	●	Electricity is a known substance and universally available. Charging stations are provided with numerous safety features.
8d	Vehicle fueling Infrastructure	○	Charging stations available in limited area only or at owner residences. Gasoline engine capability if charging station unavailable.
ID	**Societal Improvement Readiness Criteria**	**PEV with gas Rating 2011**	**Plug-in Electric with Gasoline Range Extension Research**
9a	Vehicle EOL Disposition	○	Batteries can be recycled, but the extent is undetermined at this point. The rest of the vehicle is identical to gasoline vehicles.
10a	Local Air Quality / Tailpipe Emissions	●	No tailpipe emissions when operating on electricity alone. LEV if operating on gasoline engine to recharge.
10b	Petroleum use reduction	●	Significant reduction in petroleum to operate, however upstream impacts of electricity generation need to be addressed.
10c	Fuel renewability / resource depletion	●	Electricity is 100% renewable.
10d	Energy independence	●	Electricity production is primarily domestic.

10e	Carbon footprint	●	Significant reductions possible, however, upstream impacts of electricity generation need to be addressed.
11a	Change in driver behavior	○	Some change in driver behavior to accomplish charging actions. Adjustments required for location of charging stations.

7.8 Hydrogen ICE Vehicles

A hydrogen ICE vehicle operates by combusting gaseous hydrogen in a conventional ICE engine. Hydrogen research conducted for this program is in Appendix D. The following table summarizes the rating for each criterion, and the supporting documentation and reasoning.

ID	Technology Readiness Criteria	HICE Rating 2011	Hydrogen Internal Combustion Engine Research
1a	Vehicle Acquisition Cost	▣	There are no production HICE vehicles available for purchase. There are conversions available from gasoline ICE to hydrogen ICE available. These conversions significantly add to the purchase price of the vehicle. Example: Total price of vehicles converted to HICE for RIT was $115,000 per vehicle.
1b	Fuel Economy-Cost Per Mile	▣	Cost per mile is significantly higher than gasoline or diesel due to the limited availability of hydrogen as a motor fuel. Research by RIT indicates that the miles per gallon of gas equivalent for hydrogen is approximately 42 highway and 34 city (as reflected in the HICE Final Report).
1c	Scheduled maintenance / service cost	○	RIT operation of the HICE vehicles over a two-year period indicated that scheduled maintenance was roughly on par with high performance vehicles
1d	Unscheduled maintenance / repair cost	○	Operation of the HICE vehicles over a two-year period resulted in several unscheduled maintenance events, repairs and replacements. Most of these were covered by a warranty from the manufacturer, but significant labor was involved to make the repairs.
2a	Single Fill up Maximum Trip Duration / time between fill ups	○	Single trip distance of the HICE vehicles operated by RIT showed a maximum range of 120 miles under ideal conditions, 100 miles under normal conditions. This is adequate for daily commuting but insufficient for extended trips. Larger fuel tank capacity is required for longer range.
2b	Continuous Operation Maximum Trip Duration	●	Operation of the HICE vehicles over a two year period did not show any vehicle technology limitations to an extended trip over 24 hours.
2c	Clean air / Vehicle tailpipe emissions	⬆	Measured emissions from the tailpipe of the HICE vehicles showed only small amounts of emissions, in the single digit ppm. (HC- 8ppm, NOx-ppm)
2d	Geographic operating restrictions	○	Operation of the HICE vehicles in a four-season environment showed a drop in vehicle performance in hot weather conditions due to the lower power provided by hydrogen vs gasoline.
3a	Vehicle scheduled service interval (scheduled time in shop)	○	Scheduled service intervals (oil changes) were approximately the same as an existing gasoline vehicle if driven on a regular basis.
3b	Vehicle fueling operability / fill time	◉	Fill time for the RIT HICE vehicles from a standard hydrogen fueler was 20-25 minutes. This can be increased to approximately 5 minutes with a "fast fill" station. Training is required to use either system.
3c	Refueling system design stability	○	The vehicle side of the refueling receptacle is standardized, but there are two different nozzle designs for 350 and 700 bar systems.
4a	Vehicle operational Safety	◉	The modified HICE vehicles have been crash tested and certified for on-road use all over the U.S.
4b	Fuel Operational Safety, Human Health	◉	There are no health hazards with hydrogen fuel, but extra safety precautions are required due to explosive nature of the fuel.
4c	First responder safety	◉	Special training was required for first responders in the area where the HICE and fuel cell vehicles were operated.
5a	Vehicle production volume capacity	▣	HICE vehicles are currently not in production, but conversion kits are available for some vehicle types – sedan, truck, bus. Conversion technology is based on mature natural gas designs.
5b	Availability of critical materials for vehicle production	●	Materials are all similar to gasoline vehicle.
5c	Tech readiness of Vehicle	●	HICE vehicles could be maintained and supported with existing equipment

	Maintenance / Support Infrastructure		and infrastructure used to support gasoline vehicles.
ID	**Commercial Readiness Criteria**	**HICE Rating 2011**	**Hydrogen Internal Combustion Engine Research**
6a	Long term fuel stability, storage, life	↑	As long as sufficient pressurization is maintained, Hydrogen fuel is stable and can be stored indefinitely without degradation.
6b	Station Technology / Infrastructure cost	□	Cost estimate for "fast fill" station is $1M. For regular station, it is approximately $500K as reflected in the actual costs for the RIT on campus station.
7a	Current vehicle production volume	□	Only a few hundred HICE conversions have been produced. Production volume is constrained by limited demand more than technology.
7b	Cumulative # of vehicles on the market. Actual market impact.	□	Only a few hundred HICE conversions are on the road.
7c	Vehicle Maintenance / Support Infrastructure	●	Vehicles can be maintained by the existing automotive support infrastructure as long as technical data and manuals are provided.
8a	Fuel production capacity / available energy within infrastructure	□	Hydrogen is currently being produced as an industrial gas via several different methods. Production in volume for use as a motor fuel will require significant investment in additional infrastructure.
8b	Bulk fuel distribution infrastructure	○	As a gas, hydrogen must be transported by special trucks and cannot be shipped by pipeline. It can also be made on site via electrolysis.
8c	Fuel delivery and handling safety	○	Although there is an explosion risk with hydrogen, it is not persistent and disperses into the air quickly.
8d	Vehicle fueling Infrastructure	□	There are only a few dozen hydrogen fueling stations currently in the U.S. Most of these are limited to fleet use and not open to the general public.
ID	**Societal Improvement Readiness Criteria**	**HICE Rating 2011**	**Hydrogen Internal Combustion Engine Research**
9a	Vehicle EOL Disposition	○	Vehicles are constructed essentially the same as gasoline vehicles, except for the high pressure fuel storage tanks. Current disposition methods would be adequate to recycle HICE components.
10a	Local Air Quality / Tailpipe Emissions	↑	When hydrogen is used in HICE vehicles, the tailpipe emissions fall into the SULEV category. All emissions in the single-digit ppm.
10b	Petroleum use reduction	↑	Vehicle itself uses some petroleum for engine lubrication and grease.
10c	Fuel renewability / resource depletion	↑	Hydrogen is the most abundant element on the earth, so it is considered the ultimate in renewable fuels.
10d	Energy independence	↑	Hydrogen can be produced domestically through several different processes. However, the processes do require electricity or natural gas.
10e	Carbon footprint	↑	Hydrogen offers the potential for reduced carbon footprint.
11a	Change in driver behavior	✱	Increased fueling time and lack of fueling infrastructure (stations) makes vehicle operations more restrictive than current technology. Requires behavior change with no improvement in driving experience.

7.9 Hydrogen Fuel Cell Vehicles

A Hydrogen Fuel Cell vehicle operated on gaseous hydrogen that uses a Proton Exchange Membrane (PEM) fuel cell to convert the hydrogen to electric power to drive a traction motor. Hydrogen research conducted for this program is in Appendix D. The following table summarizes the rating for each criterion, and the supporting documentation and reasoning.

ID	**Technology Readiness Criteria**	**PEM Rating 2011**	**Hydrogen Proton Exchange Membrane Fuel Cell Research**
1a	Vehicle Acquisition Cost	□	Vehicles available only through lease in limited geographic areas. Honda Clarity currently available for 3 year lease at $600/month.
1b	Fuel Economy-Cost Per Mile	□	Hydrogen fuel is only available in limited areas. Honda advertises 60 miles per kilogram fuel economy.
1c	Scheduled maintenance / service cost	□	Maintenance costs and physical damage collision coverage included in lease.
1d	Unscheduled maintenance / repair cost	□	Maintenance costs and physical damage collision coverage included in lease.
2a	Single Fill up Maximum Trip Duration / time between fill ups	○	Range of current technology fuel cell vehicles is approximately 200-240 miles on single fillup.
2b	Continuous Operation Maximum Trip Duration	●	Early indications are that there are no restrictions to an extended trip given the availability of hydrogen fuel.
2c	Clean air / Vehicle tailpipe emissions	⬆	Zero Emissions Vehicle.
2d	Geographic operating restrictions	□	Although fuel cell vehicles are being tested in all climates, currently they are only available for lease in moderate climates.
3a	Vehicle scheduled service interval (scheduled time in shop)	□	Limited number of vehicles available to consumers. No firm data on scheduled service interval for FC specific components.
3b	Vehicle fueling operability / fill time	◉	Fill time for the PEM FC vehicles from a standard hydrogen fueler was 20-25 minutes. This can be increased to approximately 5 minutes with a "fast fill" station. Training is required to use either system.
3c	Refueling system design stability	○	The vehicle side of the refueling receptacle is standardized, but there are two different nozzle designs for 350 and 700 bar systems.
4a	Vehicle operational Safety	◉	The FC vehicles have been crash tested and certified for on-road use all over the U.S.
4b	Fuel Operational Safety, Human Health	◉	There are no health hazards with hydrogen fuel, but extra safety precautions are required due to explosive nature of the fuel.
4c	First responder safety	◉	Special training was required for first responders in the area where the HICE and fuel cell vehicles were operated.
5a	Vehicle production volume capacity	□	Fuel Cell technology is not mature enough for high volume production.
5b	Availability of critical materials for vehicle production	○	Key constraint is availability of platinum for use in PEM fuel cells. According to a report prepared for the U.S. DOE in 2003, The platinum industry has the potential to meet a scenario where FCVs achieve 50% market penetration by 2050, while an 80% scenario could exceed the expansion capabilities of the industry. Recycled platinum from the transportation sector will be an increasingly critical source of supply.[59]
5c	Tech readiness of Vehicle Maintenance / Support Infrastructure	○	Vehicle must be maintained by specialized dealer support structure.
ID	**Commercial Readiness Criteria**	**PEM Rating**	**Hydrogen Proton Exchange Membrane Fuel Cell Research**

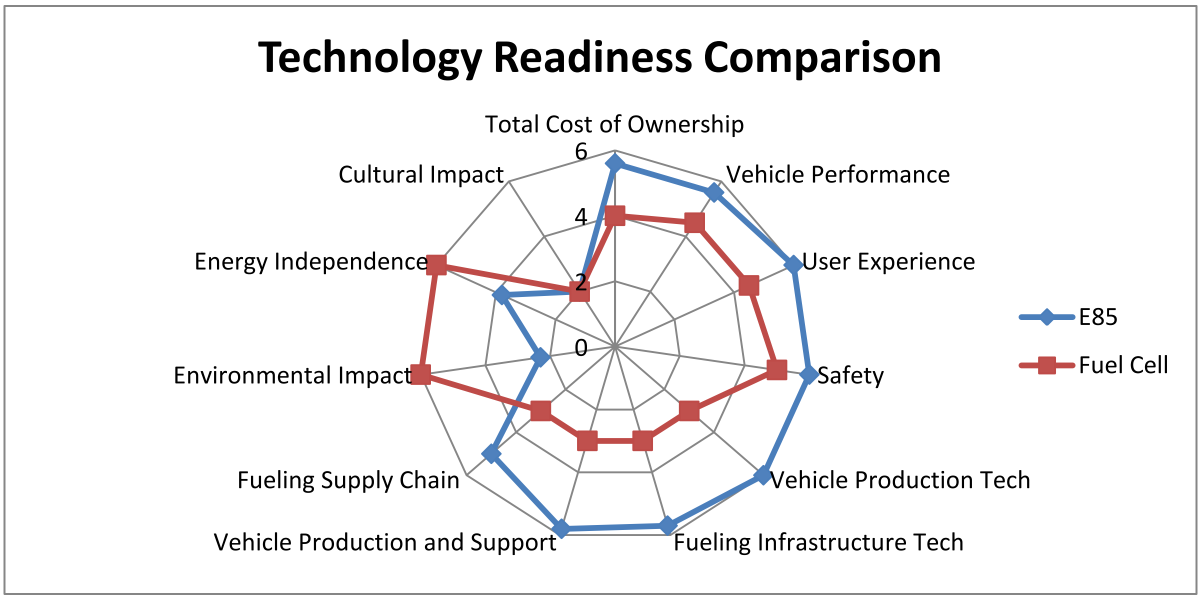
		2011	
6a	Long term fuel stability, storage, life	⬆	As long as sufficient pressurization is maintained, Hydrogen fuel is stable and can be stored indefinitely without degradation.
6b	Station Technology / Infrastructure cost	◘	Cost estimate for "fast fill" station is $1M. For regular station, it is $500K.
7a	Current vehicle production volume	◘	Only a few hundred fuel cell vehicles have been produced, primarily by hand.
7b	Cumulative # of vehicles on the market. Actual market impact.	◘	Only a few hundred fuel cell vehicles are on the road as technology demonstrators.
7c	Vehicle Maintenance / Support Infrastructure	✖	Vehicles cannot be maintained by the consumer and must be serviced by a specialized dealer infrastructure.
8a	Fuel production capacity / available energy within infrastructure	◘	Hydrogen is currently being produced as an industrial gas via several different methods. Production in volume for use as a motor fuel will require significant investment in additional infrastructure.
8b	Bulk fuel distribution infrastructure	○	As a gas, hydrogen must be transported by special trucks and cannot be shipped by pipeline. It can also be made on site via electrolysis.
8c	Fuel delivery and handling safety	○	Although there is an explosion risk with hydrogen, it is not persistent and disperses into the air quickly.
8d	Vehicle fueling Infrastructure	◘	There are only a few dozen hydrogen fueling stations currently in the U.S. Most of these are limited to fleet use and not open to the general public.
ID	**Societal Improvement Readiness Criteria**	**PEM Rating 2011**	**Hydrogen Proton Exchange Membrane Fuel Cell Research**
9a	Vehicle EOL Disposition	○	According to a report for the U.S. DOE in 2003, recycled platinum from the transportation sector will be an increasingly critical source of supply.
10a	Local Air Quality / Tailpipe Emissions	⬆	The only emission from the tailpipe of a PEM FC vehicle is water. Listed as a Zero Emissions Vehicle.
10b	Petroleum use reduction	⬆	Vehicle itself uses no petroleum other than lubricating oil and grease, however, petroleum is used in vehicle production.
10c	Fuel renewability / resource depletion	⬆	Hydrogen is the most abundant element on the earth, so it is considered the ultimate in renewable fuels.
10d	Energy independence	⬆	Hydrogen can be produced domestically through several different processes. However, the processes do require electricity or natural gas.
10e	Carbon footprint	⬆	Hydrogen offers the potential for reduced carbon footprint
11a	Change in driver behavior	✹	Increased fueling time and lack of fueling infrastructure (stations) makes vehicle operations more restrictive than current technology. Requires behavior change with no improvement in driving experience.

8 Discussion of Results and Recommendations

The use of the technology readiness assessment allows us to now evaluate the technologies against each other across a range of features and attributes. By doing this, we hoped to identify certain "centers of gravity" where readiness might be advanced the furthest with the least amount of resources, and therefore achieve the greatest reduction in petroleum dependency in the shortest time. Using that principle, we have developed some recommendations.

The basis for these recommendations is partially subjective, but colored by the realities of the U.S. light and medium duty fleet as it currently exists. The question we posed is, "What if there was a massive application of funds to solve the petroleum problem, where is the best place to use those resources?" The level of funding we assumed would be equivalent to another "Apollo Program" – the national effort to put men on the Moon and return them safely. Between 1959 and 1973 NASA spent $23.6 billion on human spaceflight, exclusive of infrastructure and support, of which nearly $20 billion was for the Apollo lunar program.[60] In FY 2011 dollars that would be well over $100 billion.

Figure 1: Technology Readiness Comparison of E85 to Hydrogen Fuel Cell



If the U.S. as a nation decided to spend $100 billion on alternatives to petroleum, what could be achieved? Based on the comparison in Figure 1 above, hydrogen fuel cell infrastructure is not technology ready. Investing in infrastructure could mean the construction of 100,000 new fast-fill hydrogen stations at $1M per station. As of August 2010, there were 159,000 retail gasoline stations in the U.S.,[61] so this funding would only replace 2/3 of them with hydrogen capability. It could also provide for millions of electric charging stations throughout the U.S. for electric vehicles. Both these projects could go a long way to reducing the 'range anxiety' associated with these new technologies.

During the period of our study, several technologies emerged that had previously been rather dormant. Diesel automobiles have are enjoying something of a renaissance in the form of

Clean Diesel technology. Gone are the rattley, smelly diesels remembered by many buyers from the 1980s. They have been replaced by high-mileage, high-powered vehicles that bear little resemblance to their earlier ancestors. These super efficient engines, when paired with biodiesel fuel blends offer the promise of excellent highway performance, increased fuel mileage and reduced emissions. Our research has shown that biodiesel can be a 'drop in' replacement for petroleum, requiring no modifications to the vehicle to use it. This is a tremendous advantage that offers flexibility in blending with regular diesel. It is also currently being made from a wide range of feedstocks, including waste vegetable oil. If a program of funding was available to increase the 'auto-diesel' pumps at service stations, more biodiesel could be made available to regular consumers.

Compressed natural gas (CNG) is also attracting a lot of attention, particularly in the Northeast U.S. – particularly New York and Pennsylvania - where the Marcellus Shale formations are forecast to hold significant reserves and where exploration is currently underway. At present there are only a few light duty CNG vehicles available for purchase (Honda sedans and GM vans) but conversion technology is available and kits are being produced and offered for a range of other vehicles. Although funds were not available on this program for a thorough study of the technology readiness of CNG vehicles, we believe this would be a worthwhile analysis. The prospect of significant natural gas reserves in the U.S. which could now be released by more modern technology could dramatically alter the energy equation in the nation. The opening of new domestic sources for energy would lessen the dependence on foreign energy sources and offers the promise of increased employment in a time of a slow economy. What is needed, though, is a program to extract the energy that does not disturb surrounding communities or groundwater. One hundred billion dollars applied to the concept of "hydrofracking" (pumping a fluid and a propping material such as sand down the well under high pressure to create fractures in the gas-bearing rock) could result more efficient and environmentally benign extraction methods. It could also be used to repair roadways in areas affected by truck traffic required to support natural gas drilling, or to reroute the traffic altogether. This would then clear the way to use CNG more widely as an auto fuel. The technology to use it is mature, but the fuel is not widely available.

If the funding was used to put the infrastructure in place for a variety of new fuels, the difficulty that remained would be to incentivize the public to purchase the new technology vehicles and use them. Overall, the U.S. general public has not raced to embrace alternative fuels or technologies. Consumers who buy flex fuel vehicles are often unaware that they can actually use E-85. News articles and op-ed pieces about ethanol in general have been overwhelmingly vitriolic. Although any light duty diesel vehicle can use biodiesel fuel, it is generally unavailable at fueling stations in most areas of the county. Sales of the Chevy Volt in the first few months of 2011 have been disappointing to say the least. Although GM sales projections were for 10,000 Volts to be sold in 2011, by the end of September 2011 they had sold less than 4,000. In September alone, GM only sold a mere 723 Volts.[62] All this despite a $7500 tax credit for purchasing one. People will not abandon what they have come to know and trust unless they see a significant benefit.

With 240 million petroleum-fueled, light-duty vehicles on the road in the U.S., perhaps it is unrealistic to believe that they can all be replaced by some other technology within one generation, or even several generations. The first practical steamship came along at the beginning of the 19th century, but it took almost a hundred years to switch most shipping from sails to steam. And even with that, sailboats are still in use today and have not been totally replaced. Developing a replacement for petroleum fuels will need to consider some type of side-by-side strategy where both fuels are available in sufficient quantities to affect a changeover before gasoline or diesel is withdrawn from the market, or reduced to a small share the petroleum required.

This situation argues strongly for different types of "bi-fuel" vehicles that can accept and operate on more than one fuel – either mixed or separately. These bi-fuel vehicles are already available in some forms – Flex Fuel (gasoline/ethanol), bi-fuel (CNG/gasoline), hythane (hydrogen/CNG) or gasoline/electric (Chevy Volt). Based on the research from this program, we believe this is the primary, practical and workable solution to reduction in petroleum usage. This recommendation is based on several findings:

- It is not practical to wholesale replace 240 million light duty vehicles-worth of petroleum with a new type of fuel without a generational investment in infrastructure.
- To be sustainable, the replacement of the 240 million existing vehicles must to some degree rely on recycling their components into a new fleet.
- Replacement of the existing light duty fleet with new technology will undoubtedly have to take into account "grandfathering" nearly new vehicles until they reach the end of their service or economic life.
- The infrastructure for petroleum would need to ramp down gradually as the infrastructure for new fuels ramps up. This also affects the workforce in the existing petroleum industry – conversion here would also be necessary.
- Consumers would be more readily accepting of a conversion kit than a requirement to purchase a whole new vehicle simply to operate on a new fuel. This as long as the kit was tested and certified to be reliable.
- Range anxiety would be moderated by the availability of a "backup" fueling source in the event of an emergency or unplanned occurrence.
- Bi-fuel systems might help to negate the disadvantages of alternative fuels such as reduced cold weather performance or decreases in fuel mileage.

With bi-fuel vehicles on the road, it allows for an orderly transition from petroleum to a new fuel. As one gas station closes down, it allows for another one to open dispensing a new product. The consumer then is able to gradually convert from one to the other with enough time to adjust to the change. The change then becomes evolutionary rather than revolutionary.

This approach also reinforces the need for a “broad front” national strategy to solve the petroleum dependence situation. It allows groups and organizations with special expertise to focus on their corner of the problem and increases the chances of multiple breakthroughs or game changing developments.

Figure 2 below from Toyota illustrates this point. This chart shows gasoline and diesel at a clear disadvantage: Both come from only one source, from oil wells. Biofuels such as ethanol and biodiesel are similarly restricted. However, electricity and hydrogen can be made from a multitude of sources.

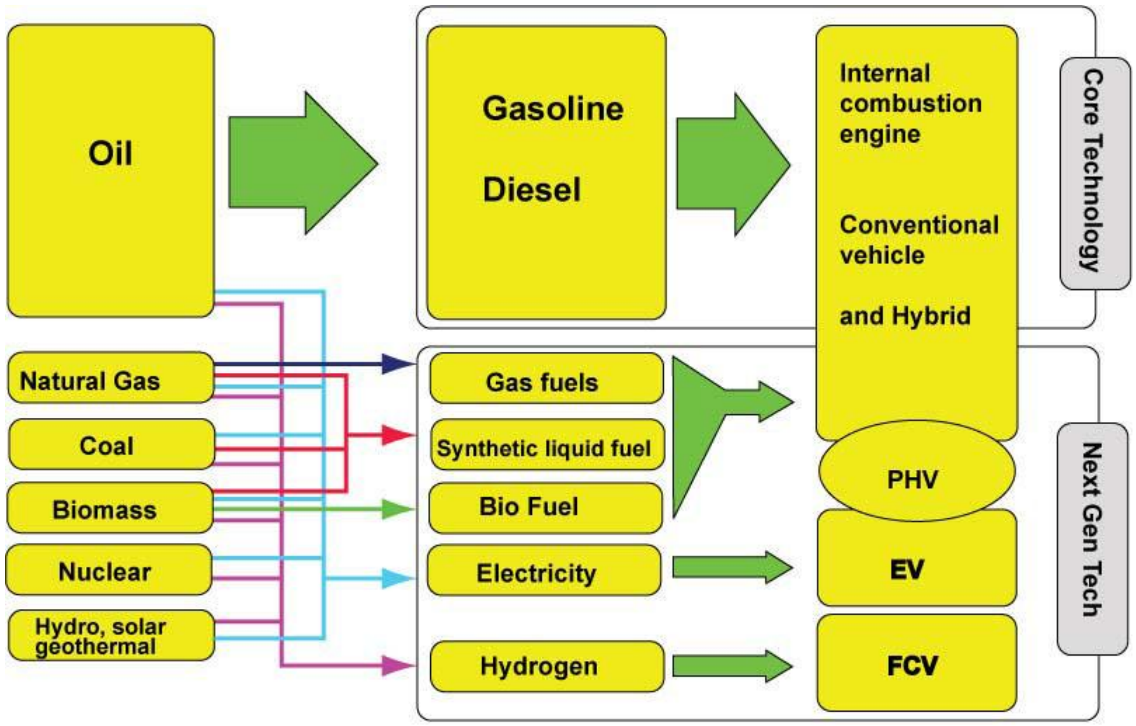


Figure 2. Fuel Pathways for Future Vehicles[63]

But funding makes these rocket ships go up, and unfortunately, "No bucks, no Buck Rogers."[64] As mentioned in the introduction, due to new CAFÉ standards, auto manufacturers are now bound to devote their limited research resources to improving the existing internal combustion engine vehicles, at the expense of striking out on new pathways for alternative fuels. This approach, ironically, is forcing the industry to focus *more* on petroleum rather than less, almost moving the needle in the wrong direction. At a time when we want auto companies to move away from petroleum, the U.S. Government is forcing them to spend more time, resources and effort on it. In fact, as this report was in the final stages of completion, yet another increase in fuel mileage standards was announced. The administration has published new rules to hike fuel economy regulations for the 2017-25 model years that nearly double requirements to 54.5 mpg.[65]

At the time this final report was being prepared, the national price of gasoline had risen to a two year high of $4 per gallon, but then dropped back into the mid-$3 range. The ups and downs of fuel prices will likely continue and no immediate substitutions are available. In order to stabilize this situation and permit the introduction of new fuels to replace petroleum, the U.S. needs a coherent national energy policy that examines the total system and allows all options to remain on the table, including energy exploration on domestic lands.

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