



# A COMPREHENSIVE SURVEY OF EMERGING TECHNOLOGY FOR NEW YORK METROPOLITAN AREA



## Technical Memorandum 4: Shortlist of Emerging Technologies

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## 1 Summary

In task 2, a comprehensive, initial list of emerging technologies to improve transportation systems was prepared. In task 3, the technologies identified in task 2 were screened based on preliminary criteria that include: a) relevance to NYMTC, and b) subjective estimate of economic and technical feasibility. Two internet accessible surveys were created for the purpose of obtaining input from the Regional Transportation Plan committee members. An important result from the first survey is the ranking of the different policy sub-categories. The second survey, feasibility assessment questionnaire included both technical and economic feasibility. The rankings for the sub-categories and the economic and technical feasibility of the technologies obtained in task 3 were taken as input in task 4 to determine the shortlist of emerging technologies that could plausibly be used.

The methodology for shortlisting technologies was based on a ranking procedure using the input obtained from RTP committee members and experts in earlier tasks. A weighted sum method was used to obtain the rankings of the technologies. Since the focus on technologies have always been toward meeting the three broad goals of congestion reduction and management, safety and security, and energy and environmental impact mitigation, three separate shortlists for each of these broad goals were prepared.

Based on the ranking of the technologies and the project team's reality-checks, five technologies each in Congestion Reduction and Management, Safety and Security, and Energy and Environment category policy areas were short-listed.

The shortlisted technologies include:

### **Congestion Reduction and Management**

- Geographic Positioning Systems and Personal Travel Assistants
- Adaptive Ramp Metering
- Smart Cards and RFID
- Personalized Rapid Transit
- Collaborative Technologies

### **Safety and Security**

- Vehicle-to-vehicle and Vehicle-to-Infrastructure Communication (DSRC, RFID, VANETs)
- Machine Vision
- MEMS and Nanosensors
- Automated Vehicles
- Biometric Identification

### **Energy and Environment**

- Natural Gas and Propane
- Biogas
- Bio-diesel and Ethanol
- Electric-driven and Hybrid vehicles
- Hydrogen Fuel

Detailed description of the short-listed technologies and the database is also presented.

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## 2 Introduction

In task 2, a comprehensive, initial list of emerging technologies to improve transportation systems was prepared. In task 3, the technologies identified in task 2 were screened based on preliminary criteria that include: a) relevance to NYMTC, and b) subjective estimate of economic and technical feasibility. The screening process was a two-stage process where in the first stage the most appropriate goals of NYMTC was screened, and in the second stage the technologies useful for achieving the goals was screened.

Two internet accessible surveys were created for the purpose of obtaining input from the Regional Transportation Plan committee members. An important result from the first survey is the ranking of the different policy sub-categories. Energy consumption is the highest ranked policy sub-category followed by transit-system improvements. Highway system improvements, transportation demand management strategies (including telecommuting), ITS, and highway safety are ranked next. These rankings will be used as weights to rank each of the specific technologies from the comprehensive list to obtain a shortlist for task 4.

The second survey, feasibility assessment questionnaire included both technical and economic feasibility. The top 5 technologies in terms of the joint technical and economic feasibility measure are GPS, HD video conferencing, machine vision, ultra-low sulfur diesel, and bio-diesel fuel.

The rankings for the sub-categories and the economic and technical feasibility of the technologies obtained in task 3 were taken as input in task 4 to determine the shortlist of emerging technologies that could plausibly be used in the New York Metro region. Below, we describe the methodology for determining the shortlist and subsequently provide details of each shortlisted technology.

## 3 Methodology for Short-listing Technologies

The methodology for shortlisting technologies was based on a ranking procedure using the input obtained from RTP committee members and experts in earlier tasks. Task 3 report outlined the exhaustive list of technologies, the survey questionnaires, and their results. Two questionnaires were used to get importance ratings for the NYMTC goals and policies and technical and economic feasibility of the different technology. Table 1 in Task 3 report (shown below) lists the ranking of the NYMTC goals and policies.

<u>Rank</u>	<u>Goal/Policy Sub-Category</u>	<u>Total Points</u>
1	Energy consumption	43
2	Transit system improvements	42
3	Highway system improvements	41
3	Transportation demand management strategies	41
3	Intelligent transportation systems	41
3	Highway safety	41
7	Pedestrian and bicycle system improvements	40
7	Pedestrian and biker safety	40
7	Traffic management	40

7	Transit security	40
7	Air Quality Improvement: Vehicle based technology	40
7	Air Quality Improvement: Fuel technology	40
7	Air Quality Improvement: Transportation infrastructure technology	40
14	Road weather management	39
14	Water and land pollution	39
16	Access management strategies	38
16	Traffic incident management	38
16	Emergency medical services	38
16	Highways security (including bridges and tunnels)	38
16	Noise pollution	38
21	Auto passenger safety	37
22	Vehicle safety	36
23	Work zone management	35
23	Freight security	35
25	Parking management strategies	34
26	Planned special events traffic management	33

Note: 9 total responses.

The second questionnaire obtained input on the technical and economic feasibility of each of the 46 technologies. The table below presents the re-scaled (-4 to +4 => 1 to 5) economic and technical feasibility ratings.

<b>Table 2 Economic and Technical Feasibility Ratings</b>		
<u>Technology</u>	<u>Economic Feasibility</u>	<u>Technical Feasibility</u>
Adaptive ramp metering	3.78	4.05
Advanced route guidance systems	4.00	4.24
Augmented Reality	3.00	2.89
Automated Container Transport system	2.89	3.38
Automated Guided Vehicles	2.89	3.67
Automated vehicles	2.56	3.00
Biobutanol Fuels	3.53	3.56
Biodiesel Fuel	4.33	4.52
Biogas Fuels	4.20	4.14
Biometric Identification	3.44	3.67
Carbon-based nano-fibres	3.33	3.76
Collaboration software	4.00	4.24
DSRC	3.56	4.24
Electric driven vehicles	3.56	4.33
Ethanol Fuel	3.89	4.05
Flying cars	1.22	1.10
Fuel-cell Nano Catalyst	3.53	3.56
GPS	5.00	5.00
HD video conferencing	4.11	5.00
Hybrid vehicles	3.67	4.90

Hydrogen Fuel	2.56	3.48
Hydrogenation-Derived Renewable Diesel	3.00	3.67
Machine Vision	4.33	4.62
MEMS sensors	3.67	3.95
Methanol Fuel	3.56	3.67
Nano Fuelsaver	3.33	3.76
Nanocoating of metallic surfaces	3.78	4.05
Nanomaterials in pavements	3.11	3.19
Nanoparticle-reinforced materials	3.67	3.48
Nanosensors	3.44	3.57
Nano-sized batteries	3.11	3.95
Natural gas	4.00	4.24
Personal travel assistant	4.00	4.33
Personalized rapid transit	3.11	3.86
Pick-up centers	3.27	4.11
Propane	3.93	4.11
P-Series	4.00	3.53
Radio Frequency Identification (RFID)	4.11	4.33
Small wheeled transport	3.56	3.86
Smart Cards	3.33	3.57
Ultra high-speed Internet	3.78	4.43
Ultra-low sulfur diesel	4.33	4.56
VANETs	3.67	3.78
Waterbridge	3.11	3.57
Wide area wireless communication	4.00	4.52

The project consultant team rated on 1-5 scale (5 being very important) each of the above technologies with respect to their importance under each of the NYMTC policy objectives listed in Table 1. These ratings together with the two ratings in Table 1 provided the importance rating matrix. The complete rating matrix is provided in Appendix 1.

A weighted sum method was used to obtain the rankings of the technologies. A weighted sum method is a simple multi-criteria decision making tool. Given  $n$  alternatives and  $m$  criteria, each alternative is provided a rating value for each criterion. This generates an  $n \times m$  data matrix. If the  $m$  criteria are assigned weights given by  $w$ , then the weighted sum for each technology can be obtained using the following formula:

$$r_i = \sum_{j=1}^m a_{ij} w_j$$

The overall ranking of the technologies can be obtained by sorting with respect to the  $r_i$  values.

Since the focus on technologies have always been toward meeting the three broad goals of congestion reduction and management, safety and security, and energy and environmental impact mitigation, three separate shortlists for each of these broad goals were prepared. The ratings for policies in Table 1 were converted to an exponential scale ( $\exp(\text{rating} - \text{minimum rating}) = \exp(\text{rating} - 33)$ ) to reflect the inherent bias that was observed in the survey responses; almost all respondents rated all the policies as important. The weights were subsequently obtained by taking a sum-average. The policies were further divided

based on the above broad goals. Economic and technical feasibility were given individual weights of 20% each and the remaining 60% were distributed to the policy objectives in each broad goal category. The rankings of the technologies and the weighted sum rating values for each of the broad categories are presented in Table 3.

**Table 3** Ranking of Technologies

**Congestion Reduction and Management**

GPS	4.74
Personal travel assistant	4.00
Radio Frequency Identification (RFID)	3.89
Adaptive ramp metering	3.46
Smart Cards	3.43
Personalized rapid transit	3.25
DSRC	3.16
MEMS sensors	3.13
Wide area wireless communication	3.09
Machine Vision	2.98
Advanced route guidance systems	2.96
Small wheeled transport	2.84
Biometric Identification	2.77
HD video conferencing *	2.68
VANETs	2.67
Automated vehicles	2.66
Ultra high-speed Internet *	2.56
Hybrid vehicles	2.49
Collaboration software *	2.41
Electricity	2.35
Hydrogen Fuel	1.98
Nanosensors	1.85
Nano-sized batteries	1.70
Nanoparticle-reinforced materials	1.54
Augmented Reality	1.38
Automatic healing materials	0.94
Flying cars	0.94

**Safety and Security**

Machine Vision	3.75
Nanosensors	3.66
DSRC	3.53
MEMS sensors	3.48
VANETs	3.46
Radio Frequency Identification (RFID)	3.11
GPS	2.89
Automated vehicles	2.66
Adaptive ramp metering	2.60
Nanoparticle-reinforced materials	2.55
Wide area wireless communication	2.35

Advanced route guidance systems	2.20
Personal travel assistant	2.03
Biometric Identification	1.96
Automatic healing materials	1.88
Nano-sized batteries	1.86
Smart Cards	1.78
Carbon-based nano-fibres	1.74
Augmented Reality	1.20
<b>Energy and Environment</b>	
Ultra-low sulfur diesel	4.46
Natural gas	4.33
Biogas Fuels	4.32
Propane	4.29
Electricity	4.26
P-Series	4.19
Nano Fuelsaver	4.10
Biobutanol Fuels	4.07
Hydrogenation-Derived Renewable Diesel	4.01
Nano-sized batteries	3.97
Hydrogen Fuel	3.89
Hybrid vehicles	3.88
Ethanol Fuel	3.73
Advanced route guidance systems	3.69
Methanol Fuel	3.62
Small wheeled transport	3.53
Biodiesel Fuel	3.41
HD video conferencing	3.35
Wide area wireless communication	3.24
Automated vehicles	3.23
Personal travel assistant	3.20
Adaptive ramp metering	3.17
Ultra high-speed Internet	3.17
Fuel-cell Nano Catalyst	3.05
DSRC	1.64
VANETs	1.57

Telecommuting technologies marked with a \*

#### 4 Short-listed Technologies

Based on the ranking of the technologies in Table 3 the top 5 technologies in each category were selected. Few of the technologies that overlapped or jointly formed a technology "system" were grouped; for example, smart cards use RFID chips and therefore they were combined. Additional technologies were added to the list based on the project team's reality-checks. We discuss this process of selection and the rationale for choosing some technologies which were not necessarily in the top five.

In Congestion Reduction and Management the top five technologies were Geographic Positioning Systems (GPS), Personal Travel Assistants, RFID, Adaptive Ramp Metering, and Smart Cards. Since GPS were an integral part of personal travel assistants the two technologies were combined to form a single technology system. Similarly, RFID and Smart Cards were combined since RFID is the primary mode of recognition in smart card systems. Two additional technologies Personal Rapid Transit and Collaborative technologies were added to the list to bring the total list of technologies to five. Personal Rapid Transit was chosen since it was ranked sixth in the list. Three technologies listed HD Video Conferencing, Ultra high speed internet, and collaborative software together comprises collaborative technologies. These technologies together act as telecommuting enablers. Since the RTP committee members expressed that telecommuting is an important policy focus, these technologies were grouped together and included in the shortlist as collaboration technologies. The technologies are identified based on their likelihood of being implemented in the NY metropolitan area.

The top five Safety and Security technologies were: Machine Vision, Nanosensors, Dedicated Short-Range Communication, Micro-Electronic Mechanical Systems Sensors (MEMS), and Vehicular Ad-hoc NETWORKS (VANET). Nanosensors and MEMS represented sensor technologies though at different size scales. Since the overall objective of these technologies was sensing they were grouped together into a single category. Similarly DSRC and RFID are likely to be an important component in VANET. Further, vehicle to infrastructure communication is developing alongside vehicle to vehicle communication. These technologies were grouped together into vehicle to vehicle and vehicle to infrastructure communication technologies. The technologies that were added to the list subsequently were automated vehicles and biometric identification. GPS technologies was not included since the project team believe even with improvements to GPS technologies, the accuracy (and more importantly relative positions between objects and vehicles) may not be sufficient for safety applications. Further, automated vehicles are likely to incorporate GPS and all of the other technologies ranked above. Preliminary models of automated vehicles that incorporate adaptive cruise control and lane departure warning are already available in the market and are likely to grow steadily in the future. Therefore, automated vehicles technology was included in the shortlist ahead of GPS. Finally, with increasing emphasis on security, biometric identification – a promising security technology – was also added to the shortlist.

The top technologies in Energy and Environment policy category were primarily fuel technologies. Ultra-low sulfur diesel, natural gas, biogas, propane, and electricity were the top five technologies in this category. Ultra-low sulfur diesel (ULSD) which was the top-most technology in the Energy and Environment category has already become a widely established fuel alternative. Therefore it has not been included in the list of "emerging" technologies. ULSD is diesel fuel with 15 parts per million (ppm) sulfur content. Ultra-low sulfur diesel enables use of advanced emission control technologies on light-duty and heavy-duty diesel vehicles. Effective June 1, 2006, 80 percent of the highway diesel fuel produced or imported is required to be ULSD fuel replacing most Low Sulfur Diesel (LSD) fuel, which contains a maximum of 500 ppm sulfur. Used in combination with cleaner-burning diesel engines and vehicles, ULSD fuel helps to improve air quality by significantly reducing emissions. By December 1, 2010, all highway diesel fuel offered for sale must be ULSD fuel (23). Natural gas and propane which had several similarities were grouped together. Hybrid vehicles (ranked 12) was included along with electric vehicles since they share several common technology components and hybrid development is likely to help advanced electric vehicle development. Finally, two other technologies – Hydrogen fuel (ranked 11) and Ethanol/Bio-diesel (ranked 13 and 17) were included to the list because of

their predicted market potential in the long-term and near-term respectively. Hydrogen fuel received a lower ranking primarily because of the low score it received based on the technical and economic feasibility. The cost of fuel cell stacks has decreased tenfold in just three years (121). Improvements in technology are likely to bring the cost down further. In the longer term – 20 to 30 years – with rising cost of traditional fuel sources hydrogen fuel holds greater promise. Ethanol and Bio-diesel received lower rankings primarily because of the threat to food-security they pose. Nevertheless, in the next 10 years, they are likely to play the role of dominant alternative fuel source (105) since they are easily compatible with existing vehicle engines and have therefore been included in the shortlist.

**Table 4 Shortlisted Technologies**

**Congestion Reduction and Management**

Geographic Positioning Systems and Personal Travel Assistants  
 Adaptive Ramp Metering  
 Smart Cards and RFID  
 Personalized Rapid Transit  
 Collaborative Technologies

**Safety and Security**

Vehicle-to-vehicle and Vehicle-to-Infrastructure Communication (DSRC, RFID, VANETs)  
 Machine Vision  
 MEMS and Nanosensors  
 Automated Vehicles  
 Biometric Identification

**Energy and Environment**

Natural Gas and Propane  
 Biogas  
 Bio-diesel and Ethanol  
 Electric-driven and Hybrid vehicles  
 Hydrogen Fuel

## 5 Detailed Description of Short-listed Technologies

### 5.1 Congestion Reduction and Management

#### 5.1.1 Geographic Positioning Systems and Personal Travel Assistants

**Description and Features:** Geographic positioning systems (GPS) provide accurate location coordinates. While GPS devices have become common use, the next generation of such devices will have the following characteristics:

- Miniaturization
- Increased accuracy
- Supplementary location technologies to cover GPS-denied areas (inside buildings, or downtown streets)

Early GPS technology was bulky and cumbersome and was suitable only for use by skilled personal for survey techniques. However over the last decade GPS technologies have become portable and have enabled advanced navigation capabilities for the everyday traveler. Initially,

GPS were equipped in vehicles and personal navigation devices that provided in-vehicle route guidance for users. More recently GPS has become available on cellular phones. In fact it is anticipated that every cellular phone to be produced from the later part of 2008 will be equipped with integrated GPS. This miniaturization of GPS has allowed for anywhere anytime location-awareness for users. Among other benefits, these devices serve as personal travel assistants that can guide users to make optimal travel decisions.



**A Personal Navigation Device**

Personal travel assistants provide individuals, in vehicles and on foot, with location based information services. It brings together several features including navigation, traffic information, as well as utility and entertainment through stand-alone GPS or mobile phones. Initially, network-based location technologies from cellular service providers relied on triangulation using cell-tower signals to determine individual location; This method is increasingly giving way to leveraging built-in GPS chips in each handset, mostly because these chips have become dramatically more cost-effective and less power consumptive while improving location availability over the last several years (1). For example, Texas Instruments has recently integrated GPS with Bluetooth and FM transmission capabilities in a single-chip. Intelligent

power consumption technology will enable cell-phones provide all of the capabilities simultaneously for extended periods of time.

Another important development is the possibility of greater accuracy. The GPS modernization project as well as the European Union's plan to implement an alternative complementary satellite navigation system will increase the accuracy and reliability of GPS tracking. Galileo will provide greater accuracy than GPS ( $\pm 4$  meters, compared with  $\pm 10$  meters for commercial applications) because of the greater number of signals available.

**Timeline:** Both the GPS modernization project and the Galileo satellite system is expected to be operational by 2013.

ABI Research said personal navigation devices (PNDs) will grow to a global sales volume of more than 100 million units by 2011. ABI Research expects the market for GPS-enabled handsets to grow strongly in the next five years, from around 140 million handsets in 2007 to more than 600 million handset shipments in 2012.

In-Stat predicts that "Sales of mobile devices with integrated GPS [will] grow from 180 million units in 2007 to 720 million units in 2011."

**Costs:** The cost of PNDs and GPS equipped Handsets is comparatively high. However, these prices are expected to reduce in the future.



The cost of PNDs ranges from \$200 to \$1200. The cost of GPS enabled handsets ranges from \$400 to \$800. Handsets without in-built GPS have the option to add Bluetooth GPS receivers for \$50 - \$150. Further, subscription services to obtain real-time traffic updates are available from \$5 per month to \$10 per month.

**Transportation Applications:** More accurate GPS enables better navigation systems. Mobile and wearable GPS allow for better personal navigation and quicker emergency response. GPS may also aid in collecting travel behavior data (2) that could be used in building models for planning and operations.

Real-time information on traffic delays enables personalized public transit information system, advanced route guidance capabilities. Multi-modal information applications: Personalized multimodal trip planning, continuous on-trip information to multimodal travelers, information on transfers, assist travelers in finding their way to the destination address once they get off at the last stop provided by public transport. (3)



**Dash's 2-way internet-connected Navigator**

Real-time information can also be utilized to update travelers about dynamic toll prices. The availability of accurate up-to-date information will enable travelers make more optimal decisions and seek alternate plans thereby increasing the efficiency of congestion pricing schemes. Most PNDs and Handheld navigation devices feature some form of subscription service to real-time information services.

### 5.1.2 Adaptive Ramp Metering

**Description and Features:** Adaptive ramp metering includes algorithms that ensure efficient traffic flow by controlling number and frequency of vehicles entering the freeway system through on-ramp signals. Broadly, these algorithms can be divided into three categories: local ramp metering algorithms, system-wide coordinated ramp metering algorithms, and a combination of the two. The following material is borrowed mostly from the paper by Rafferty and Treasize (4).

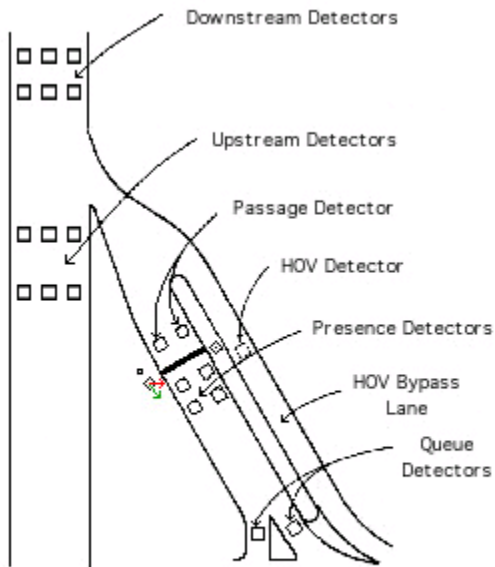
#### *Local Ramp Meter Algorithms*

Local control is a process of selecting ramp meter rates based solely on conditions present at an individual ramp. In some cases, congestion problems at the ramp may appear to be fixed, when in reality problems are transferred to or uncovered at upstream or downstream locations.

- **ALINEA.** The control input is based on the system output. The goal of ALINEA is to sustain near maximum flow downstream of the on-ramp by regulating the downstream occupancy to a target value, which is set a little below the critical occupancy at which congestion first appears.
- **ALINEA/Q.** This algorithm extends ALINEA by calculating a second rate: the minimum rate needed to keep the ramp queue at or below the maximum allowable queue length.
- **FL-ALINEA.** FL-ALINEA uses flow measurements from downstream detectors instead of occupancy measurements.
- **MALINEA.** MALINEA addresses a shortcoming of ALINEA by also measuring the upstream occupancy.
- **UF-ALINEA.** It uses the sum of the upstream flow and the ramp flow to estimate the downstream flow.
- **UP-ALINEA.** Uses occupancy measurements, but from upstream detectors, and estimates the downstream occupancy.
- **X-ALINEA/Q.** This is where any of the modified ALINEA algorithms are used with queue control. All of these algorithms, except for X-ALINEA/Q are less efficient than the

traditional ALINEA algorithm but are useful when various occupancy measurements are not available.

- **Demand-Capacity.** This traffic responsive algorithm measures the downstream occupancy. If it is above the critical occupancy, congestion is assumed to exist. The metering rate is then set to the min rate. Otherwise, the volume is measured upstream of the merge, and the metering rate is set to the difference between the downstream capacity and the upstream volume.



Metered Freeway Ramp Source: (5)

the merge, and the metering rate is set to the difference between the downstream capacity and the upstream volume.

- **Fixed-Rate or Time-of-Day.** Ramp meter timings are adjusted automatically by specified time-of-day parameters. This algorithm does not afford flexibility for changing traffic conditions.

- **Percent-Occupancy.** This strategy uses only upstream sensor occupancy measurements to identify and measure congestion. The critical occupancy is measured using historical data.

#### System wide Coordinated Ramp Meter Algorithms

This is a process of selecting metering rates based on conditions throughout the entire length of the metered corridor. This makes system wide control more flexible in handling reductions in capacity that occur as a result of congestion or non-recurring incidents.

- **ARMS (Advanced Real-time Metering System).** ARMS works on two levels. In the first level, a system wide control policy is to maintain free flow conditions. A prediction and pattern recognition algorithm is also developed to predict in real-time the potential occurrence of recurrent congestion. In the second level, the algorithm works to resolve congestion once it develops. It does this by minimizing the congestion clearance time and queues on the controlled ramps.
- **BEEX (Balanced Efficiency and Equity).** BEEX seeks to minimize the total weighted travel time, which involves weighting both the freeway mainline travel time and the ramp delays.
- **Fuzzy Logic.** It can balance several performance objectives simultaneously, such as occupancy, flow rate, speed, and ramp queue. The performance objectives are divided into finite categories and then rules are developed with different weighting factors to relate traffic conditions with metering levels. Fuzzy logic can anticipate a problem and take temperate, corrective action before congestion occurs. With congestion indicators as inputs, the Fuzzy Logic can handle poor data, incidents, special events, and adverse weather without modifying the control parameters.
- **Linear.** The linear algorithm maximizes the weighted sum of ramp flows. It also computes a real-time capacity for each road segment. The drawbacks of this algorithm are (a) its performance is heavily dependent on accurate origin-destination data, and (b) it is static, i.e., it neglects the variation of travel time in its computation of ramp metering rates.

- **METALINE.** The metering rate of each ramp is computed based on the change in measured occupancy of each freeway segment under METALINE control and the deviation of occupancy from critical occupancy for each segment that has a controlled on-ramp.
- **Metering model for non-recurrent congestion.** It has a dynamic traffic flow model to describe the traffic flow process, explicitly links control with a clear set of objectives, takes into account system wide physical and environmental constraints and projected traffic conditions, and uses a rigorous yet straightforward solution procedure to obtain real-time metering rates.
- **MILOS (Multi-Objective, Integrated, Large-Scale, & Optimized System).** The area wide coordinator assigns target ramp metering rates to maximize freeway throughput, balance ramp queue growth rates, and minimize queue spill-back into the adjacent surface street interchanges.
- **SZM (Stratified Zone Metering).** Effective in reducing ramp delays and queues, reducing freeway travel time and delay, increasing freeway speed, smoothing freeway flow, as well as reducing the number of stops.

#### *Local and System wide Coordinated Ramp Meter Algorithms*

The following algorithms have both local and coordinated capabilities.

- **Bottleneck.** For each ramp, the more restrictive of the two rates is chosen. Local: A control strategy compares the upstream demand with the downstream supply; then takes the difference of them as the locally determined metering rate. System wide: A coordinated control strategy first identifies bottlenecks, decides the volume reduction for the bottleneck based on flow conservation, and then distributes the volume reduction to upstream ramps according to predetermined weights.
- **Compass.** The more restrictive of the following two rates is selected. Local: Determines the metering rates from an ad-hoc lookup table, which has multiple levels for each ramp, determined by the local mainline occupancy, the downstream mainline occupancy, and the upstream mainline volume. System wide: Coordinated control use of off-line optimization to generate metering rates based on system wide information. Compass addresses spillback through overriding restrictive rates. If the occupancy at a ramp queue detector exceeds its threshold value, the metering rate is increased by one rate level until the detected occupancy is back below the threshold level.
- **Dynamic metering control.** Local control attempts to maintain traffic conditions close to the target traffic conditions that are provided by area-wide control. It obtains metering rates through minimizing the total system travel time that includes travel time on freeway and delay on ramps, subject to demand and queue capacity constraints.
- **FLOW.** FLOW tries to keep traffic at a predefined bottleneck below capacity and works best at very high traffic volumes. The more restrictive of the following two rates is chosen. Local: The metering rates associated with each upstream occupancy are the difference between the capacity and volume associated with the occupancy on the fundamental diagram. System wide: For the bottleneck metering rate, bottleneck locations on the freeway must be determined. The bottleneck metering rate for each ramp is then calculated by subtracting the bottleneck metering rate reduction from the measured on-ramp flow during the previous interval.
- **Helper (or incremental).** A freeway corridor is divided into six groups consisting of one to seven ramps per group. Local: In the local traffic responsive metering component, each meter selects one of six available metering rates based on localized upstream mainline occupancy. System wide: If a ramp grows a long queue and is classified as critical, its metering burden will be sequentially distributed to its upstream ramps.

- **Linked.** Local: It is separated into a number of local traffic responsive controllers. This algorithm is based on the demand-capacity concept, and the local metering rate is determined based on upstream flow measurement at each location where the metering rate is equal to the target flow rate minus the upstream flow rate. System wide: Whenever a ramp's metering rate is in one of its lowest three metering rates, then the upstream ramp is required to meter in the same rate or less, and, if necessary, the further upstream ramps are also required to do so.
- **Neural Control.** Local: This algorithm uses feedback regulation to maintain a desired level of occupancy, or the target occupancy, which is usually chosen to be the critical occupancy. Moreover, the neural control algorithm is limited in adaptive control if on-line tuning is not implemented. System wide: This uses artificial neural networks to learn and memorize the metering plans generated by a traffic simulation model and a ramp control expert system.
- **RAMBO (Ramp Adaptive Metering Bottleneck Optimization).** Local: RAMBO I evaluates plans generated based on ramp metering specifications. System wide: RAMBO II evaluates ramp metering rates based on forecasted traffic conditions along an extended section of freeway containing up to 12 metered on-ramps and 12 exit ramps. RAMBO II develops ramp metering rates using capacity and merge constraints for the entire freeway segment specified by the user.
- **SWARM (System Wide Adaptive Ramp Metering).** SWARM has to stay within a TOD max and min range. The most restrictive rate is selected for each ramp. Local: The local control decides ramp metering rates based on local density. System wide: When a bottleneck is detected, a new set of ramp metering rates are determined. Downstream ramp meters will be shut off and upstream ramp meters will have a more restrictive timing. SWARM has the potential to be proactive, rather than reactive. It has a built-in failure management module to clean faulty input data from detectors. It also allows further adjustment to accommodate queue spill-back handling. It automatically adjusts timing for incidents and holidays.
- **ZONE.** Local: Zone provides for local control by using the occupancy control philosophy. System wide: ZONE divides a freeway into several zones of three to six miles in length. The upstream end of a zone is a free-flow area, whereas downstream end of a zone is a critical bottleneck. ZONE calculates metering rates based on volume control in each zone. To accomplish this, ZONE relies on proper division of zones, accurate estimates of bottleneck capacity, and accurate measurements of all in- and out-flows from a zone. (4)

According to the Federal Highway Administration, evaluations from across the country show that ramp metering reduces collisions on freeways and ramps from 15 to 50%. Ramp management strategies often increase travel speeds while reducing travel time and delay. Freeways that have metered entrance ramps usually carry more traffic than they did before metering began while attaining the improvements mentioned previously. The table below provides a brief summary of common measures of effectiveness for ramp metering (4).

**Timeline:** Ramp metering is currently implemented across the United States and Europe. (5) Also, new algorithms are being developed which will be more efficient than the current algorithms.

**Table 1. National ramp meter benefits (WisDOT 2006)**

City	Study road	Speed increase	Travel time reduction	Crash reduction	Flow increase	Program initiation
Minneapolis	I-35	26%	-	- 27%	25%	1970
Portland	I-5	61%	12 min	- 43%	-	1981
Seattle	I-5		11.5 min	- 39%	62%-86%	1981
Long Island	Multiple	9%	-	- 15%	2%	1989
Detroit	I-94	8%	-	-50%	14%	1982
Austin	I-35	60%	-	-	7.9%	Late 1970s
San Francisco	I-80	-	- 1 min	-	14%	1974
Denver	I-25	57%	37%	-5%	-	1981
Milwaukee	US-45	6%-13%	5%	-16%	-	1969

Source: Rafferty and Treasize (4)

**Costs:** Costs to the implementing agency include the development and calibration of metering system algorithms as well as infrastructure and maintenance expenses. In addition, a control center may be desired to monitor the system as a whole. The cost of a particular ramp metering system varies widely according to the sophistication of the algorithm used to set the metering rate and the number of ramps included in the system. Potential costs to the public are: (5)

- Undesirable levels of traffic diversion to surface streets
- Increased emissions and/or fuel consumption at ramps
- Ramp delay and spillback onto surface streets
- Promotion of longer trips
- Transfer of land values

**Transportation Applications:** Benefits include the following:

- Travel time savings
- Improved safety
- Effective use of capacity
- Reduced travel time variability (5)
- Air quality improvements owing to smoother traffic flow.

As long as the target level of service (LOS) could be maintained through the regulation of ramp meters, the more congested the traffic condition is, the more effective the adaptive ramp metering control can be. (6)

**Challenges/Drawbacks:**

If the congestion becomes severe and the target LOS could not be maintained by using ramp metering, the effectiveness of adaptive ramp control is marginal. (6)

ZONE can work with fixed bottlenecks only, which need to be identified during the pre-implementation phase based on historical traffic conditions. (6)

Implementation of ramp metering is almost always initially opposed by the public because of increased queues at on-ramps. The most successful programs have instituted large campaigns to educate the public on the benefits of ramp metering. In addition to this initial opposition, equity issues may arise due to the fact that ramp metering often promotes longer trips over shorter ones. This problem may be addressed by adjusting metering rates. Finally, existing ramps must have enough capacity to accommodate increased ramp queues without causing excessive spillover onto the surface street network. If ramps do not already have this capacity, construction costs can be formidable. (5)

### 5.1.3 Smart Cards and RFID

**Description and Features:** A Radio-Frequency Identification tag (RFID tag) is an electronic chip that can be applied to any object for the purpose of identification using radio waves. RFID tags can be classified as passive (only read data) or active (read and write data). Passive tags have practical read distances ranging from about 10 cm (4 in.) up to a few meters. Active tags typically have much longer range (approximately 500 m/1500 feet) and larger memories than passive tags. EZ Pass - a type of RFID tag - has been extensively used in the Northeastern US for the past 15 years.

Smart cards are pocket sized cards with RFID tags and embedded integrated circuits which can process information. Examples in transportation include: Oyster card in London and Octopus card in Hong Kong. Advantages of using smart cards in public transit ticketing include: reduced passenger/staff fraud levels, reduced delays at entry gates, improved cash handling procedures, reduce staff handling costs, improved staff utilization, and flexibility in fare policies (7). These advantages primarily accrue from the contact-less nature of the technology. The RFID transponders in the cards enable users to simply tap their card close to the readers and walk through the gates without having to stop.

In the future, it is anticipated that RFID transponders as well as Smartcards will become increasingly common methods of toll and fare payments. Improvements in efficiency will enable use of RFID transponders in open road tolling where vehicles are not required to slow down to record toll transactions.

Smartcards will become the preferred method for transit fare payments. The Smart Card Alliance (8) lists five potential contactless transit fare payment methods:

- Traditional fare payment systems that incorporate a stored value model. These systems use contactless smart cards to carry a data file that is read and updated by readers. The data file includes all of the information about the electronic token or pass purchased by the customer that is required for the reader to calculate transaction-specific charges. To date, implementations throughout the world have used this model, including U.S. transit systems in Washington, D.C.; Baltimore; San Francisco; Oakland; Los Angeles; Chicago; San Diego; Seattle; Minneapolis; Houston; Boston; Philadelphia; Atlanta; and the New York–New Jersey area.
- Traditional payment card industry systems that use existing financial networks to process transactions and load value onto traditional fare payment cards. Transit agency devices such as ticket vending machines and point-of-sale (POS) systems are simply merchant terminals that process fare payment transactions just as they would any other retail transaction. It is common for most medium and large transit agencies in the United States to accept credit and debit card payment for some or all fare products sold.



**A pay-pass based key fob used by NYC MTA**

- Enhanced payment card industry systems that incorporate an intermediate back office step. This step calculates the correct fare before the transaction is processed through traditional financial networks. These systems sometimes aggregate transactions to reduce transaction fees. An example of this model is the New York City Transit pilot program (9), which accepts contactless credit and debit transactions for paying subway fares. The Utah Transit Authority has conducted a pilot program, which accepted contactless credit and debit transactions for paying bus fares, and is now launching a full system bus/rail deployment using this approach.
- Basic combined systems that use contactless media. With this system, the contactless payment media carry two types of data files. One is the transit application data file used in traditional fare payment systems. The other is the credit/debit cardholder information needed to process transactions using traditional financial payment card industry systems. The two payment systems are not integrated in any way at the card level. The transit



**London Oyster/Barclay Card**

- application is used to pay for transit fares; the credit/debit card application is used for other retail purchases. Examples of this model are the London Oyster/Barclaycard and the Taipei EASYCARD.
- Enhanced combined systems that give customers a choice of fare payment methods. Methods include the contactless fare card used in traditional fare payment systems, the multi-application card used in basic combined systems, and the standard credit or debit card used in traditional financial payment card industry systems.

The Smart Card Alliance has two white papers on two of the methods of payments: the first (10) discusses the direct acceptance of American Express, Discover, MasterCard, and Visa contactless payment products. The second (11) discusses the *basic combined system* described above.

**Costs:** The price of RFID tags has fallen, from around \$2 each in 1999 to around \$0.10-0.15 today [2007] (12). Typical costs of Smartcards range from \$2.00 to \$10.00.

**Transportation Applications:** In addition to the above applications Smartcards can be used for secure identification (e-passport) (13), security personnel identification at ports (14), parking systems (15), and other financial transactions (16).

The major benefits to customers of smart cards have included (17): 1) the availability of features such as registration/balance protection, employer autoload, and negative balance; 2) the ability to use the same card on multiple operators; and 3) the improved convenience of the contactless interface, i.e., the card does not have to be removed from a wallet or purse. Potential benefits of smart cards for customers include multi-application capabilities (e.g., use of the card for non-transit purposes) and innovative fare options (e.g., WMATA's planned Fair Fares strategy, which would guarantee that the customer is paying the "lowest possible fare" for each ride). Users of smart cards have expressed generally high levels of satisfaction with the cards and programs. For instance, in Chicago, 93% of survey respondents were satisfied or very satisfied with the cards, and 86% expressed willingness to continue using the card after the conclusion of the pilot period and to recommend the card to others. In the TransLink program, both survey respondents and focus group participants expressed a high level of satisfaction with the program. Moreover, two-thirds of noncard users surveyed said that they are "very likely" to try the card. Sales of the

SmarTrip card in Washington have grown steadily since its introduction, despite the fact that WMATA has done very little marketing of the program.

#### 5.1.4 Personalized Rapid Transit

**Description and Features:** PRT system includes fully automated vehicles capable of operation without human drivers over a reserved guideway. The vehicles are available on-demand, direct origin to destination service for an individual or a small group - typically 1 to 6 passengers. (18)

The key characteristics of PRT include (19):

- On-demand, origin-to-destination service
- Small, fully-automated vehicles
- Exclusive-use guideways
- Off-line stations
- A network or system of fully-connected guideways

In terms of the carrying capacity, the following chart prepared by one of the companies developing PRT systems (Taxi 2000) provides an estimate.

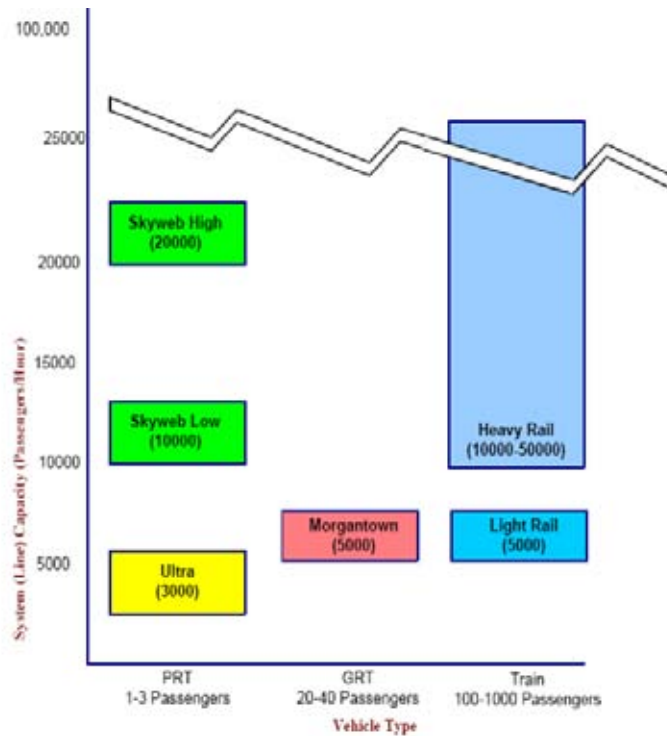
A report by the Advanced Transit Association (20) is the best on the state-of-the-art of PRT systems. Another report (19) on viability of PRT for New Jersey provides an excellent evaluation of implementing PRT in a state neighboring New York State. The conclusions from this study are:

- PRT systems are approaching but not yet ready for public deployment.
- Many of the technical components needed to support PRT systems are commercially available and are used in other industries
- Global PRT interest and development programs are expanding
  - An active test track in Cardiff Wales and a joint development program between ULTra and the British Airport Authority for an installation at Heathrow Airport;
  - A comprehensive development program including test tracks in Sweden and Korea for the Vectus system;
  - A prototype vehicle and section of guideway in Minnesota as well as a small-scale network model for the SkyWeb Express system in the United States; and
  - An extensive test track (not currently operating) that verified system technology and operation of the Cabintaxi system.
- A fully operational PRT system is needed to demonstrate the theoretical benefits of PRT and establish commercial readiness.
- A comprehensive technology research and demonstration program is needed to develop a PRT system.



ULTra

**Timeline:** The first completely operational PRT system (ULTra) will debut at the Heathrow Airport London in Spring 2009 (21). Several other PRT variants are at different stages of development. The Morgantown transit system which has been in successful operation for over 30 years is an example of a variant of PRTs referred to as Group Rapid Transit. A completely deployed PRT system will successfully allay the fears and doubts that are currently withholding planners from implementing them. Almost all studies indicate PRTs are highly beneficial particularly in densely developed urban centers such as Manhattan and other counties that are a part of NYMTC.



Source: <http://www.taxi2000.com/images/Generic1.pdf>

Responses from vendors were as follows:

System	Guideway (M\$/km)	Vehicle (k\$)	Notes, Justification
Austrans			not supplied
Autran	1.3 (e)	20	costed by principal in company
Cybertran	3.1 (bep)	100	costed by four separate large firms and based on prototypes
Frog (CyberCab)	unknown	63	based on pilot project
Higherway	2.0	unknown	preliminary estimate
MegaRail	1.3 (ep)	18	preliminary estimate
MicroRail	0.8 (ep)	15	preliminary estimate
Mitchell (ADA)	1.5 (ep)		cost based on bids by manufacturers of the prototypes
Pathfinder	12-15		includes stations; estimated by principals in company
Ruf	2.2	20	estimated by principal in company
SwedeTrack			unknown
Taxi 2000	1.6 (ep)	26	costed by a university and three other large firms
ULTra	1.5	50	actual cost of prototype
Urbanaut	4.5 (ep)		

**Notes on table – what costs are included in estimates**

(b) bi-directional

(e) electronic guideway based control system

(p) power substations, transformers

Source: Advanced Transit Association (20)

**Costs:** The total cost of an ULTra system - vehicle, infrastructure and control system - works out between £3million and £5million per km of track.

Of the 14 systems reporting cost estimates, four have actually built a prototype: Cybertran, Frog (CyberCab), Taxi 2000, and ULTra.

- For those four, guideway costs range from \$2.6M/mile for Taxi 2000 to \$5.0M/mile for Cybertran.
- Assuming a saturation level of one vehicle every 100 feet (or 50 per mile of guideway), vehicle costs range from \$2.1M/mile for Taxi 2000 to \$8.0M for Cybertran. [Note that Cybertran vehicles carry 6-20 passengers while Taxi 2000 and ULTra vehicles hold a maximum of 4 passengers. The smaller vehicles and superstructure likely account for the lower costs of both Taxi 2000 and ULTra.]
- As indicated in the "Additional component costs" on page 90, station costs can range from \$100K to \$500K per station. Stations would be ADA compliant and usually include elevators. Planning for two stations per mile would add, at most, \$1M/mile to guideway costs.
- Costs for land acquisition are excluded because public right-of-way (primarily roadways) will be used. Due to the small footprint of each supporting post (approximately 4 square feet every 60-90 feet) and the flexibility of routing, utility relocations will be minimal and relatively insignificant. Other costs might include modifying buildings, providing parking at stations, and enhancing aesthetic features. Adding an extra 10% for planning, environmental studies, and management seems reasonable.

In summary, full costing for these four systems can be expected to range from \$6.27M/mile to \$15.4M/mile. Bi-directional costs, which are useful for comparison to corridor-type transit systems, would be \$12.5M to \$31M/mile.

**Implementation or Commercial Examples:** Several models of PRT have been developed. Most of the companies that develop PRT systems are listed below (20):

**Supported, simple PRT:**

Austrans: <http://www.aebishop.com>  
Autran: <http://www.autrancorp.com>  
Cybertran: <http://www.cybertran.com/>  
Megarail/Microrail: <http://www.megarail.com>  
Mitchell  
Taxi 2000: <http://www.taxi2000.com/>  
ULTra: <http://www.atsltd.co.uk/>  
Urbanaut

**Suspended, simple PRT:**

Higherway: <http://www.artwerkz.com/h/>  
Pathfinder  
SwedeTrack: <http://www.swedetrack.com/>

**Other:**

Frog / 2getthere – <http://www.frog.nl>  
MAIT: <http://www.maitint.org>  
Ruf: <http://www.ruf.dk/>

### 5.1.5 Collaborative Technologies

**Description and Features:** Broadly collaborative technologies can be divided into three categories: communication, conferencing, and collaborative management tools. Communication technologies include e-mail, instant messaging, and VoIP. Conferencing technologies include webinars, web conferencing, and HD video conferencing. Collaborative management tools include shared electronic calendars, project management, knowledge management systems, prediction markets, and desktop sharing services such as concurrent versions system (CVS).

Different types of collaborative technologies have different features. While few of the technologies such as e-mail and instant messaging are commonly used, others are still emerging. We discuss each of these emerging technologies below.



**VoIP:** VoIP has recently emerged as the preferred calling method particularly in small and medium-sized enterprises for international calls. Current VoIP providers include Packet8, Vonage, Knightel, Vonics Digital, and BBTelsys LLC. Another VoIP/instant messaging software that has become popular is Skype. Skype requires a computer to make telephone calls while the other providers can be used both through a computer and through traditional telephones connected to a phone adapter which is linked to the internet router. Recently Skype has introduced mobile phone-like devices that enable users to tap into wireless

internet sources to place and receive Skype calls.

**Webinars:** Webinar is short for Web-based seminar that is broadcast over the Internet. A webinar allows participants to be active members contributing to the seminar. Several alternative formats are available including video/presentation and audio broadcast over the internet or audio access provided separately by telephone conference. A significant advantage of webinar software is its relative ease of use and accessibility: any user with broadband internet connectivity can participate in a webinar. Adobe Acrobat Connect, Lotus Sametime Connect, Microsoft LiveMeeting, WebEx, GoToMeeting are few examples of webinar software. Few of these software require every participant to install in his/her machine while others such as WebEx and GoToMeeting allow any individual with an internet connection and browser to participate.



**HD Video Conferencing:** The technology has created a new term to describe video conferencing: telepresence. As the term telepresence suggests, HD video conferencing provides crystal clear video images at larger-than-life-size. Currently, the technology is primarily used by high-level executives and medical professionals. However, in the future the technology could be accessible to even small and mid-level companies. HD video conferencing requires a dedicated ultra high-speed internet line, HD video cameras, and screens/monitors for

display. Presently the cost of such systems is high. Companies that produce HD video conferencing systems include: Lifesize, Polycom, Cisco, Sony, Tandberg, HP, Teliris.

**Timeline:** Most of the above technologies have already been developed and tested. However, they are still not used widely. Adoption of new technologies takes between 5 to 10 years and it is anticipated over the next decade these technologies will become commonly used.

**Costs:** Hi-definition video conferencing technologies are very expensive. For example, Cisco TelePresence costs between \$80,000 to \$299,000, Telanetix costs about \$40,000 plus the monthly cost for T-1 internet lines (>\$1000 per month), and at the lower end is Polycom's HDX-4000 at \$8000 (source: <http://www.networkworld.com/news/2007/082107-networker.html>)

Adobe Acrobat Connect: \$40/month or \$395/year  
GoToMeeting: \$49/month or \$468/month  
VoIP: \$10 - \$50/month

**Transportation Applications:** All the above collaborative technologies encourage telecommuting. Further, the collaborative technologies provide novel methods for social interaction and entertainment opportunities that can significantly alter activity-travel behaviors.

**Challenges/Drawbacks:** Costs of few of these advanced technologies are high. However, over the next 10 years these costs could significantly scale down. A more important challenge is the need for adaptability of organizations. Telecommuting requires an entirely different management paradigm and there could be significant inertia to implement these technologies.

HD video conferencing requires very large bandwidths and cannot be supported by current broadband network infrastructure. In the future, emergence of ultra-high speed internet will enable HD video conferencing.

**Implementation or Commercial Examples:** Several companies currently produce the above collaborative technologies.

**VoIP:** Packet8, Vonage, Knightel, Vonics Digital, and BBTelsys LLC, Skype.

**Webinars:** Adobe Acrobat Connect, Lotus Sametime Connect, Microsoft LiveMeeting, WebEx, GoToMeeting

**HD Video Conferencing:** Lifesize, Polycom, Cisco, Sony, Tandberg, HP, Teliris

## 5.2 Safety and Security Technologies

### 5.2.1 Vehicle-to-vehicle and Vehicle-to-Infrastructure Communication

**Description and Features:** Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication opens up several new safety applications. The Vehicle Safety Communications (VSC) project (22) was established to evaluate vehicle safety applications enabled or enhanced by communications. In 2002, seven automotive manufacturers—BMW, DaimlerChrysler, Ford, GM, Nissan, Toyota, and VW—formed the VSC Consortium (VSCC) to participate in this project with the U.S. Department of Transportation (USDOT). 34 vehicle safety application scenarios enabled or enhanced by wireless communications were identified. From the 34 application

scenarios, the VSCC identified 8 scenarios as high-priority and selected for further research based on the estimated potential safety benefits. Of these 8 application scenarios, 4 involve vehicle-to-vehicle communications and 4 involve communications between vehicles and the infrastructure. Three of the vehicle infrastructure communication applications involve intersections. The 34 applications include:

**Collision Avoidance**

- Traffic Signal Violation Warning
- Stop Sign Violation Warning
- Left Turn Assistant
- Stop Sign Movement Assistant
- Intersection Collision Warning
- Blind Merge Warning
- Pedestrian Crossing Information Warning

**Public Safety**

- Approaching Emergency Vehicle Warning
- Emergency Vehicle Signal Preemption
- SOS Services
- Post-Crash Warning

**Sign Extension**

- In-Vehicle Signage Warning
- Curve Speed Warning
- Low Parking Structure Warning
- Wrong Way Driver Warning
- Low Bridge Warning
- Work Zone Warning
- In-Vehicle Amber Alert Warning

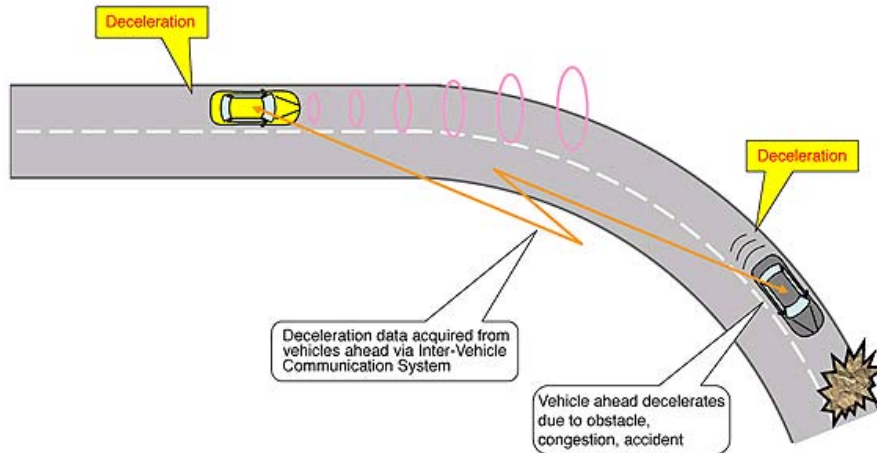
**Vehicle Diagnostics and Maintenance**

- Safety Recall Notice
- Just-in-Time Repair Notification

**Information from Other Vehicles**

- Cooperative Forward Collision Warning
- Road Condition Warning
- Emergency Electronic Brake Lights
- Lane Change Warning
- Blind Spot Warning
- Highway Merge Assistant
- Visibility Enhancer
- Cooperative Collision Warning
- Cooperative Vehicle-Highway Automation System (Platoon)
- Cooperative Adaptive Cruise Control
- Road Condition Warning
- Pre-Crash Sensing
- Highway/Railroad Collision Warning
- Vehicle-to-Vehicle Road Feature Notification
- Cooperative Glare Reduction
- Adaptive Headlamp Aiming

The primary mode of communication identified for V2V and V2I communication is Dedicated Short Range Communications (DSRC) 5.9-Ghz. DSRC applications now in use include electronic toll collection, and electronic credentialing and monitoring of commercial vehicle operations (CVO) (24).



The promise of DSRC is to deliver a far greater data rate and range to wireless highway applications. "Compared with existing RFID toll applications, DSRC will deliver data rates of 25 Megabits per second, instead of 250 kilobits, and a range of up to 1 km, instead of 10 meters," says

Unlike other sensor technologies, DSRC does not require line of sight

Source: <http://world.honda.com/news/2005/c050902.html>

Richard Schnacke, vice president of industry relations for TransCore (25).

The DSRC system supports communication links in the following parameters (26):

Vehicle speed (up to 120 mph), Communication range (up to 1000 meters for special vehicles; nominal is 300 meters), System Latency (< 50 ms), Data rate (default is 6 Mbps; up to 27 Mbps), Single transaction size (up to 20K bytes).

**Timeline:** Government and vehicle manufacturers plan to make a collaborative decision on deployment of DSRC in the year 2008 that could signal the beginning of the deployment process in the auto industry and public agencies (27). DSRC is the technology for the 2010 decade and beyond (26).

**Costs:** No cost estimates are available, but they will clearly be a lot more expensive than today's standard toll tags (9). However, it is anticipated that the costs will be absorbed by car manufacturers and the additional cost compared to cost of the automobile is likely to be low.

**Transportation Applications:** In addition to the safety applications listed earlier, V2V and V2I will enable the following non-safety related applications (22):

#### **Traffic Management**

- Intelligent On-Ramp Metering
- Intelligent Traffic Flow Control

#### **Tolling**

- Free-Flow (or Open Road) Tolling

#### **Information from Other Vehicles**

- Instant Messaging (Probe data)
- Adaptive Drive-Train Management
- Enhanced Route Guidance and Navigation
- Point-of-Interest Notification
- Map Downloads and Updates
- GPS Correction
- Real-time scheduling of transit and fleet vehicles

**Challenges/Drawbacks:** There are several challenges associated with widespread implementation of V2V and V2I technologies including:

- Privacy concerns (28)
- Sabotage
- Benefits will depend on penetration

Zimmer (28) observes that "...VSC applications is a potential rise in the ability to surveil a driver engaging in her everyday activities on the public roads... [could lead from] V2V safety technology to V2V traffic enforcement and insurance information gathering." Privacy concerns will have to be addressed before the public is comfortable with using the technology. However, if the potential benefits are significant privacy concerns are likely to be definitely addressed amicably to ensure the benefits are realized.

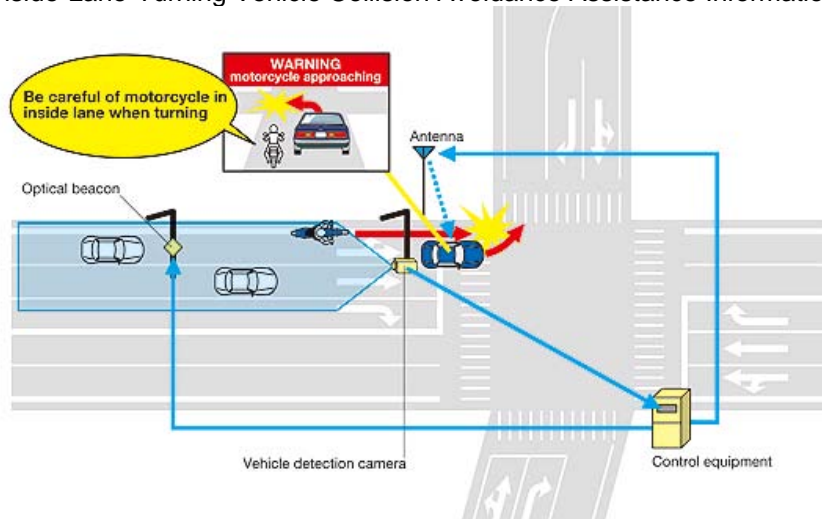
The VSCC (22) identified four types of threats of increasing empowerment related to vehicle safety communication systems' endangerment:

- Type 1: Attackers with a programmable radio transmitter/receiver
- Type 2: Attackers with access to an un-modified VSC unit
- Type 3: Attackers with access to a modified VSC unit who have obtained the keying material
- Type 4: Attackers inside manufacturing or security programming with full access

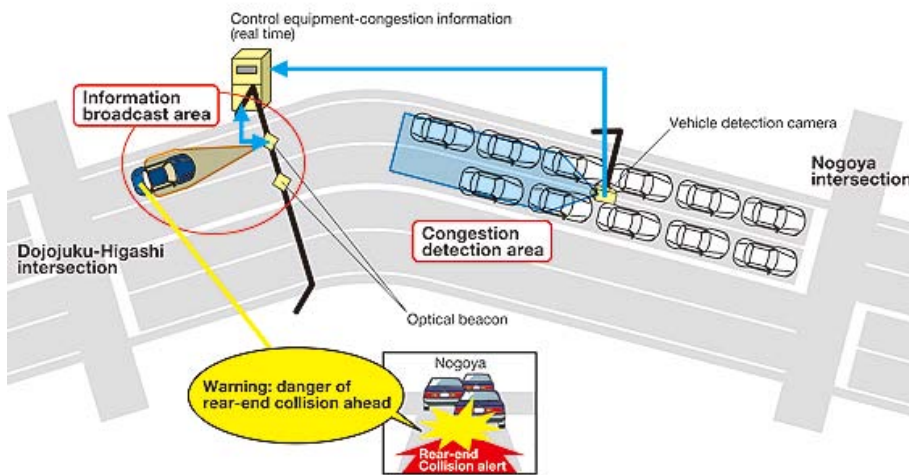
The threat model and constraints led to the core of the task—an architecture design that the VSCC believes may adequately address the identified threats while meeting the estimated constraints within this task.

- All on-board units and roadside units (RSUs) are issued certificates (OBUs are issued multiple certificates) in a special, compact format.
- The certificates for RSUs contain authorization information such as the area in which the unit is permitted to operate and the type of information it is allowed to broadcast.
- OBU certificates do not contain the permanent vehicle-identity information.
- All messages are digitally signed. Any units suspected of being compromised are put on a revocation list that is flooded to all other units.

#### Inside-Lane-Turning Vehicle Collision Avoidance Assistance Information System(ASV/DSSS)



#### Rear-end Collision Avoidance Assistance Information System (DSSS)



Source: <http://world.honda.com/news/2008/4080324Advanced-Safety-Vehicles/>

**Implementation or Commercial Examples:** GM, Honda, and Mazda among other automobile manufacturers have been testing V2V and V2I applications for several years.

## 5.2.2 Machine Vision

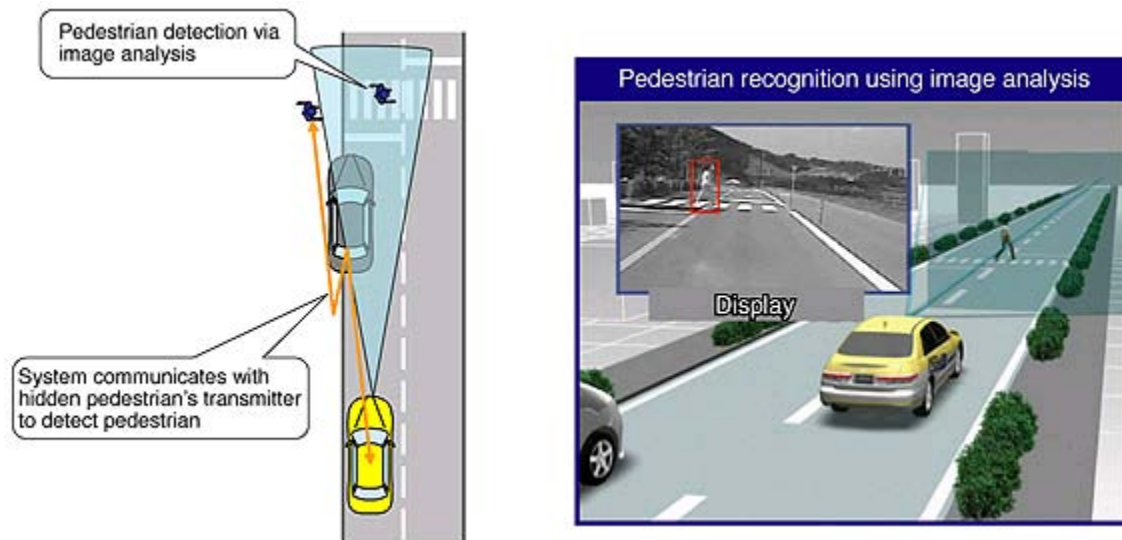
**Description and Features:** Machine vision involves the digitization, manipulation, and analysis of images, usually within a computer (29). Machine vision has been applied in industrial image processing for quality control, to identify swimmers who are drowning (30), fire alert system (31), and many more (32). However it has been applied in only limited context in transportation. For example, Saab's Driver Attention Warning System (33) utilizes two miniature infra-red cameras, one installed at the base of the driver's A-pillar and the other in the center of the main fascia, which are focused on the driver's eyes. The image from the cameras is analyzed by software that deploys a series of alerts when the pattern of eye-lid movement indicates the onset of drowsiness, or when the driver is not looking at the road ahead. Infra-red imaging is used to ensure good performance in all day and night light conditions, and even if the driver is wearing dark glasses.

**Timeline:** Most machine vision systems have already been tested and implemented. However, in transportation these systems are available only in high-end cars because of their cost.

**Transportation Applications:** Machine vision has applications in traffic monitoring, navigation, and transport safety (34). Using machine vision we can deduct lane markings, vehicles, pedestrians, road signs, traffic conditions, traffic incidents, and even driver drowsiness (35), Road/Railroad Structure Analysis, Seaport Monitoring, vehicle License/Number Plate Analysis (32). Machine vision provides more accurate classification capabilities (36) compared to other sensor types.

**Challenges/Drawbacks:** Challenges include making machine-vision systems less expensive, more compact, and more robust in various weather and traffic conditions. (5)

**Implementation or Commercial Examples:**



Source: <http://world.honda.com/news/2005/c050902.html>

Omnivision develops lane-departure detection and warning systems, blind spot displays, night vision, intelligent airbag deployment, panoramic rear view cameras, adaptive cruise control, rain detection systems and car security, which are being touted as major selling points for security and driver assistance. Improvements in component quality and reliability, and lower production costs mean that the use of cameras in automotive applications is no longer limited to high-end luxury cars and SUVs.



SafeTRAC Lane Tracker is an in-vehicle safety system that uses a forward-looking video camera to monitor the road ahead. It tracks road features to determine a vehicle's position and trajectory and generates a warning if a vehicle begins to drift out of its lane. SafeTRAC also detects drowsy or distracted driving by sensing weaving or erratic lane keeping.

Mobileye has developed core technologies in the areas of algorithms and ASIC architecture design for monocular video processing supporting driver assistance and for safety related applications such as Lane Departure Warning, Pedestrian Protection,

Adaptive Headlight Control, Traffic Sign Recognition, and additional applications. Mobileye provides its technology in six production platforms to BMW, GM and Volvo including:

- Lane Departure Warning
- LDW + Vehicle Detection + Fusion
- Driver Impairment Monitoring
- Advance Warning System
- LDW + Adaptive Headlight Control + Traffic Sign Recognition
- Collision Mitigation by braking with Pedestrian Recognition

Other commercial players include:

Iteris (Santa Ana, California): Lane departure warning systems for trucks and cars that monitor position on the road. Used in over 35,000 trucks (2007). Also creates traffic monitoring systems.

Smart Eye (Göteborg, Sweden): Systems to track eye and gaze position of a driver to detect drowsiness or inattention.

Appian Technology (Bourne End, Buckinghamshire, UK): Systems for reading automobile license plates.

AutoVu (Montreal, Canada): Systems for reading automobile license plates.

Image Sensing Systems (St. Paul, Minnesota): Created the Autoscope system that uses roadside video cameras for real-time traffic management. Over 40,000 cameras are in use (37).

### 5.2.3 MEMS and Nanosensors

**Description and Features:** Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology (38). MEMS technology have been applied to motion-based approach to navigation within and between pages in PDAs or MP3 players, in game controllers, MEMS sensors allow the player to play just moving the controller/pad (39). Sensors gather information from the environment through measuring mechanical, thermal, biological, chemical, optical, and magnetic phenomena. The electronics then process the information derived from the sensors and through some decision making capability direct the actuators to respond by moving, positioning, regulating, pumping, and filtering, thereby controlling the environment for some desired outcome or purpose (38).

*Nanosensors* on the other hand are much smaller compared to MEMS. They have potential to track bio-terror agents, stress in materials, and detect polluting agents in the atmosphere and tailpipes. Nanosensors could be used in transportation to monitor pavement conditions, bridge conditions, pollution deduction, bio-terror agent detection, air quality monitor etc. The feasibility of “Cyberliths”, or Smart Aggregates, as wireless sensors embedded in concrete or soil is being studied. Researchers at Johns Hopkins University’s Applied Physics Laboratory have developed a robust wireless embedded sensor, suitable for long term field monitoring of corrosion in rebar, particularly in bridge decks. An advantage of nanosensors over MEMS could be the significantly reduced power consumption. This allows nanosensors to be implemented in a wide scale (as “smartdust”) without having to worry about battery outage or battery maintenance.



*Apple iPhone and Wii Power Glove use MEMS sensors to determine orientation and hand movements.*

**Timeline:** Air bag accelerometers that detects the beginning of the car's sudden impact by measuring the movement of an impossibly small (.10 microgram) "mass," which then causes the air bag to fire have been in use for about 10 years (40). However future applications will have to be identified and MEMS developed for the particular applications. The technology for development is already available; what is requires is identification of specific applications that will benefit from these sensors.

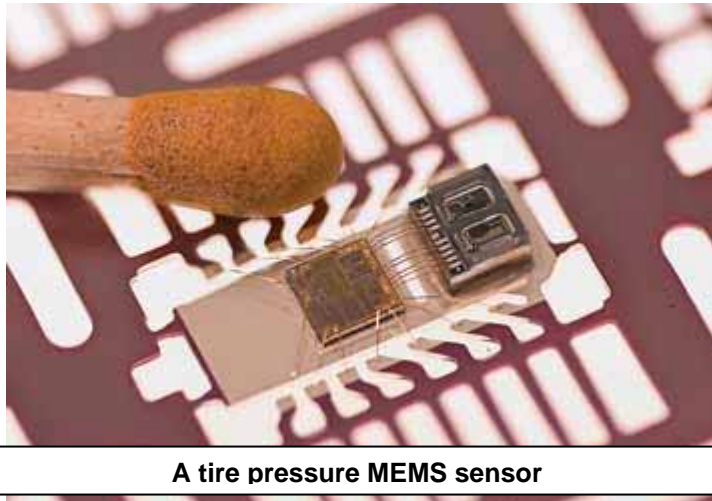
**Costs:** Because of their size and low cost, MEMS could make measurement and control strategies that were not possible with macro or discrete devices now feasible. MEMS have the problem of a high initial development cost. But once developed, MEMS can be mass-produced for a relatively low per-unit cost: \$5 to \$50 each. (41)

**Transportation Applications:** MEMS can be used in Advanced Driver Assistance Systems, Crash Detection, Electronic Stability Control, LED Taillight Driver, Navigation (42), monitoring and testing of transportation infrastructure (43). In transportation air-quality studies, MEMS "smart dust" has the potential to collect data for both analysis and forecasting the air-quality (41).

The majority of the potential MEMS applications in transportation infrastructure will act as sensors. These include sensors used in monitoring temperature, crack measurements and monitoring, corrosion testing and monitoring, alkali-silica reaction (ASR) and other related reactions in concrete, and reliability of welding units in structural steel (41).

MEMS thermal accelerometers could be used in navigation systems with maps and global positioning satellite capabilities, MEMS-based display can overlay automobile diagnostics and repair instructions directly to the technician, and seat-based MEMS for occupant deduction (42).

Crash sensing for air bag control represents the largest automotive use of inertial MEMS sensors. In this application, an accelerometer continuously measures the acceleration of the car. Vehicle dynamic control (VDC) systems help the driver regain control of the automobile when it starts to skid. If the VDC works properly, the driver may not even be aware that the system intervened. A VDC system consists of a gyroscope, a low-g accelerometer, and wheel-speed sensors at each wheel (the wheel-speed sensors may also be used by the ABS). Navigation systems



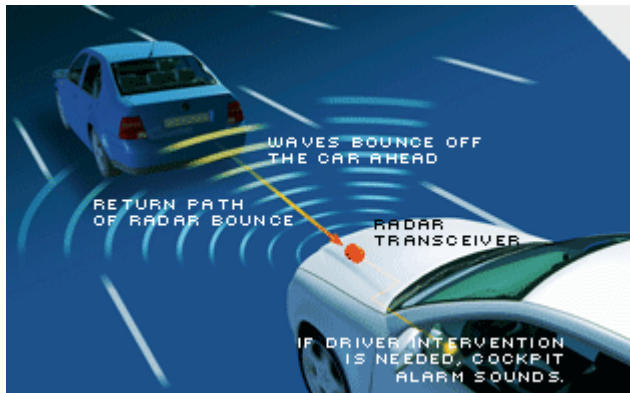
**A tire pressure MEMS sensor**

rely on compass and GPS information when the system is first started. The direction of travel is matched up with map data to give the system more certainty regarding direction. Once initial direction is established, gyroscope information is used to determine when and how much the car has turned, until directional data can be verified by map matching. In urban settings, it's not unusual for the GPS signal to be obscured by tall buildings or tunnels for short periods. At these times, the navigation system relies on the gyroscope for heading information and a low-g accelerometer for position information (43).

**Challenges/Drawbacks:** One drawback to extensive MEMS application is that MEMS products are application specific rather than generic. The vast majority of applications require solutions that necessitate the funding and completion of an evaluation or development program. In addition, the environment in which the MEMS devices has to operate and the possible effect of the environment on the performance of the MEMS device has to be assessed. Protection of the MEMS device against damage from installation or construction procedures as well as from contact with materials is paramount (41). Nanosensors are still under research; there are no commercial examples of the use of nanosensors.

## 5.2.4 Automated Vehicles

**Description and Features:** Adaptive cruise control (44), lane departure warning, collision avoidance (45, 46) are all part of intelligent or automated vehicles (47, 48). Automated vehicles include sensors to detect vehicles and obstacles, and intelligent algorithms (49) to enable these technologies. Vehicle based technology includes adaptive cruise control, lane departure warning, and collision warning devices. These have already been successfully demonstrated.



Radar-based Adaptive Cruise Control System (50)

with the slower vehicle ahead of it. Also, if a car or even a motorcycle enters the lane in front of the vehicle with adaptive cruise control at a speed of 45 mph, the equipped vehicle will detect this and immediately decelerate. (50)

**Lane Departure Warning System:** The Lane Departure Warning System detects unintentional lane departures on motorways at speeds exceeding 80 kilometers per hour. It uses the existing road markings as well as six infrared sensors under the vehicle. Lane departures are detected by variations in the reflections of the infrared beams emitted. (51)

**Collision Avoidance Technologies:** These technologies use sensors on-board vehicles or embedded in the infrastructure to monitor vehicle movements and, in some instances, the driver's behavior and process that information and either directly modify vehicle operation, warn the driver, or make adjustments to safety devices to mitigate an impending collision.

Certain types of collisions, however, are more amenable to being prevented or minimized by technologies that involve more public investment, or contribute such a significant burden to the accident rate as to justify additional research involving systems with larger public investments. For example, lane departures (resulting in lateral collisions) and intersection crashes are major

components of a National Highway Traffic Safety Administration research program for collision avoidance. (46)

**Automated Highway Systems:** An automated highway system uses magnetized stainless-steel spikes embedded in the roadway. A car is equipped with sensors and controlled by a computer in platoons to lessen congestion. The PATH project tested this technology in San Diego, California. However, the National Automated Highway System Research Program concluded that the program should not be continued, focusing on technologies that require less infrastructure (52).

**Timeline:** Many features of the technology have been demonstrated; May require more time before it becomes accepted and widely used.

Adaptive cruise control has been included with luxury cars since the end of the 20<sup>th</sup> century. (53)

Japan is farthest along in deploying autonomous, vehicle-only systems, with Europe not far behind. In the U.S., certain elements of collision avoidance and warning systems are starting to be available, but mainly on higher-priced car models. (46)

**Costs:** Adaptive cruise control is currently fairly expensive, costing \$600 per vehicle for a cheaper version and over \$2000 for systems that are more precise. (53)

Costs of these new technologies are generally passed on to the consumers, which can cause problems for implementation. (46)

Lane departure warning systems currently cost only a few hundred dollars. (54)

**Transportation Applications:** Automated vehicles can have significant impact on throughput (reduced congestion) and safety (no accidents).

Adaptive cruise control breaks backward shockwave propagation. At an average speed of 67 miles per hour, if only one in five vehicles used adaptive cruise control, no traffic jams would form and traffic would generally flow freely. However, at speeds lower than 50 miles per hour, adaptive cruise control would have no positive impact on congestion. (55)

Longitudinal collision avoidance is being studied for use in automated precision docking for buses, freight handling at ports, and semi-automated systems to guide parallel parking maneuvers. (46)

**Challenges/Drawbacks:** Application of technology in mixed traffic where only a fraction of the vehicles have the technology will be a challenge (56); lacks wide spread tests in real situations.

Systems that use alarms to warn the driver need to be accurate enough to avoid having too many false alarms that annoy the driver. In addition, drivers may over-rely on collision avoidance, causing accidents unless the system is flawless (46).



**BMW Lane Departure Warning**

Understand human-factors in using the technology (57). When real-world factors such as inclement weather, difficult terrain,

or limited visibility due to dust or nightfall are introduced, the problem of vehicle control can quickly become intractable. (58)

**Commercial Examples:** The Lexus LS includes an advance parking guidance system, which can help the driver parallel park. All that is required of the driver is selecting a parking space as well as applying the brakes. It also includes a pre-collision system with sensors that can determine if a frontal collision is imminent and helps the driver stop the vehicle). The Ford Mondeo comes equipped with Adaptive Cruise Control technology, using radar to maintain a pre-set distance from the car in front of the vehicle. Volvo has developed a system where a car will brake by itself if it realizes that the driver will not stop in time to avoid hitting a car in front of it. The Buick Lucerne includes a Lane Departure Warning that provides an audio and visual warning when the vehicle drifts into another lane. BMW also provides lane departure warning with a vibrating steering wheel.

### 5.2.5 Biometric Identification

**Description and Features:** Biometrics is the science of identifying people using physiological features. Biometric identification includes finger-print, face, DNA, hand geometry, voice, retina and Iris identification. Important characteristics of a biometric identification technology are accuracy, ease of use, user acceptance, ease of implementation, and cost (59).

*Iris Identification:* Iris recognition is a biometric identification technology that uses high-resolution images of the irises of the eye. The iris of the eye is well suited for authentication purposes. It is an internal organ protected from most damage and wear, it is practically flat and uniform under most conditions and it has a texture that is unique even to genetically identical twins. Iris recognition algorithms produce remarkable results. IrisCode, a commercial system derived from Daugman's work, has been used in the United Arab Emirates as a part of their immigration process. After more than 200 billion comparisons, there has *never been a false match*.

Iris scans are extremely accurate and can be done regardless of whether the subject is wearing contact lenses or glasses. However, it is necessary for the system to take eye lids and eye lashes into account; both can obscure the necessary parts of the eye and cause false information to be added into automated systems. (60)

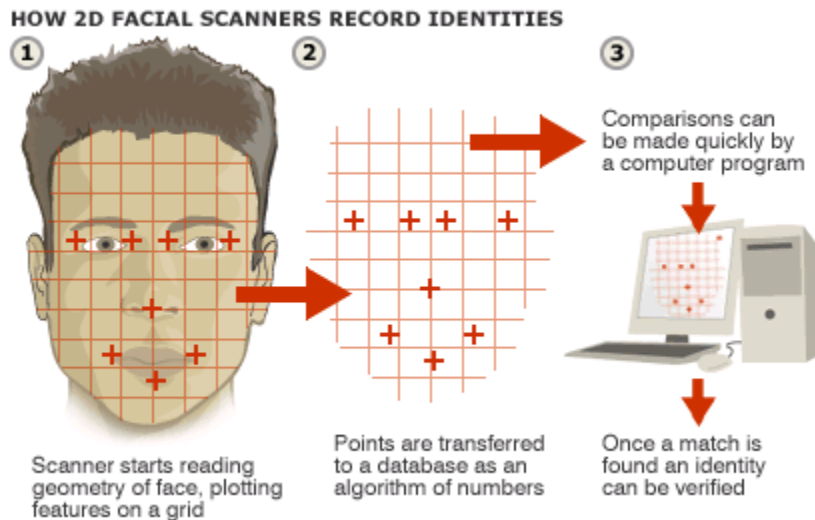


Features of iris recognition include accuracy, with an unmatched equal error rate performance of 1 in 1.2 million. The iris is also stable, with patterns remaining constant from age 1 until death. It can find nearly 20 times more matches per minute than it's closest competitor, can manage very large databases due to a small storage size required, and is non-invasive, using no bright lights or lasers and no tie-in to law enforcement fingerprint databases. (61)

*Fingerprints:* Finger printing takes an image (either using ink or a digital scan) of a person's fingertips and records its characteristics. Whorls, arches, and loops are recorded along with the patterns of ridges, furrows, and minutiae. This information may then be processed or stored as an image or as an encoded computer algorithm to be compared with other fingerprint records. To

prevent fake fingers from being used, many systems also measure blood flow, or check for correctly arrayed ridges at the edges of the fingers. Finger printing has been in use in criminal investigations for over 100 years and continues to expand every day. Fingerprint scanning secure entry devices for building door locks and computer network access are becoming more common. Recently a small number of banks have begun using fingerprint readers for authorization at ATMs and grocery stores are experimenting with a fingerprint scan checkout that automatically recognizes and bills a registered user's credit card or debit account. The potential uses for this biometric appear to be limited only by the willingness of people to use it (62).

Face Recognition: Like fingerprint biometrics, facial recognition technology is widely used various systems, including physical access control and computer user accounts security. Usually these systems extract certain features from face images and then perform face matching using these features. A face does not have as many uniquely measurable features as fingerprints and eye irises, so facial recognition reliability is slightly lower than these other biometrical recognition methods. However, it is still suitable for many applications, especially when taking into account its convenience for user. Facial recognition can also be used together with fingerprint recognition or another biometrical method for developing more security-critical applications (63).



Source: <http://news.bbc.co.uk>

Retinal Scanning: Retinal scanning analyses the layer of blood vessels at the back of the eye. Scanning involves using a low-intensity light source and an optical coupler and can read the patterns at a great level of accuracy. It does require the user to remove glasses, place their eye close to the device, and focus on a certain point. Whether the accuracy can outweigh the public discomfort is yet to be seen.

The user looks through a small opening in the device at a small green light. The user must keep their head still and eye focused on the light for several seconds during which time the device will verify his identity. This process takes about 10 to 15 seconds total. There is no known way to replicate a retina, and a retina from a dead person would deteriorate too fast to be useful, so no extra precautions have been taken with retinal scans to be sure the user is a living human being (64).

**Timeline:** The first year for the first known systematic use of fingerprint identification began in the United States is 1902. The New York Civil Service Commission established the practice of

fingerprinting applicants to pre-vent them from having better qualified persons take their tests for them. The New York state prison system began to use fingerprints for the identification of criminals in 1903. In 1904 the fingerprint system accelerated when the United States Penitentiary at Leavenworth, Kansas, and the St. Louis, Missouri, Police Department both established fingerprint bureaus. During the first quarter of the 20th century, more and more local police identification bureaus established fingerprint systems. The growing need and demand by police officials for a national repository and clearinghouse for fingerprint records led to an Act of Congress on July 1, 1921, establishing the Identification Division of the FBI. (10) The first major vendor for the research/development and production of retinal scanning devices was a company called EyeDentify, Inc., created in 1976 (65).

**Costs:** According to many security experts, iris recognition is likely the most fail-proof and high-tech security tool out there, which is why companies like Panasonic are jumping into the cargo of this possibly profitable ride. Panasonic's BM-ET200 scanner is voice activated and identifies a user within 0.3 seconds. It can hold over 10,000 user records and is priced at about \$2,500 (66). The cost of fingerprint imaging systems continues to decline. Where fingerprint imaging systems cost over \$1000 several years ago, consumers can now buy a system for under \$100 per seat (67).

**Transportation Applications:** Primary applications in transportation include for security, fare-payment, and access restriction.

A new security fast lane at Albany International Airport has lured more than 200 subscribers to the \$99.95 service. The new iris and fingerprint scan system and service was introduced at the Albany airport this week, but frequent fliers have been signing up since mid July 2007. It takes about 10 minutes at a Clear registration booth at the airport plus two to four weeks approval time by the Transportation Security Administration for the initial sign up, Brill said. The service allows members to avoid long lines at security areas where non-members are often required to remove coats and wallets (68).

Biometric recognition technology could also be used to verify employees trying to log in remotely into protected systems while telecommuting.

**Challenges/Drawbacks:** Fingerprint and retina are highly accurate; while Face recognition is not very accurate. In terms of ease of use, face and voice recognition are best suited; fingerprint and retina have low user acceptance; Iris recognition is expensive.

According to Mike Thieme, Director of Special Projects for the International Biometric Group, "In environments such as airports and open public spaces, there are three challenges: finding faces, matching faces against a database, and manually resolving 'matches' returned by the facial-scan system." Each of these steps takes time, in particular the 3rd step. "In many environments there may not be adequate time to resolve the number of false matches likely to occur in a surveillance or screening application". (69)

Concerning retinal scan devices, the cost of the proprietary hardware as well as the inability to evolve easily with new technology makes them a bad fit for most situations. It also has the stigma of consumer's thinking it is potentially harmful to the eye, and in general not easy to use. (64)

## 5.3 Energy and Environment Technologies

### 5.3.1 Natural Gas and Propane

**Description and Features:** Propane, also known as liquefied petroleum gas (LPG or LP-gas), or autogas in Europe, is a three-carbon alkane gas (C<sub>3</sub>H<sub>8</sub>). Stored under pressure inside a tank, propane turns into a colorless, odorless liquid. As pressure is released, the liquid propane vaporizes and turns into gas that is used for combustion. Propane has several advantages including (70, 71)

- Excellent properties for spark-ignited internal combustion engines.
- An exceptionally safe fuel.
- Non-toxic and presents no threat to soil, surface water, or groundwater.
- Compared with vehicles fueled by conventional diesel and gasoline, propane vehicles can produce significantly lower amounts of some harmful emissions and the greenhouse gas carbon dioxide.

Natural gas is a mixture of hydrocarbons, predominantly methane (CH<sub>4</sub>). As delivered through the pipeline system, it also contains hydrocarbons such as ethane and propane and other gases such as nitrogen, helium, carbon dioxide, hydrogen sulfide, and water vapor (72, 73). Advantages of natural gas are similar to propane mentioned above. Natural gas (74, 75) is domestically produced alternative fuel. It has a high octane rating and excellent properties for spark-ignited internal combustion engines. It provides fueling convenience. It is safe, non-toxic, non-corrosive, and non-carcinogenic. It presents no threat to soil, surface water, or groundwater. Natural gas vehicles are cleaner than most fuels. NGVs produce about 15 percent less greenhouse gases than comparable diesel vehicles, and 20 percent less than comparable gasoline vehicles.



*Home Refueling Unit "Phill"  
Courtesy of FuelMaker Corporation*

Commercial vehicles are the primary on-road consumers of diesel fuel, the use of which the Energy Information Agency (EIA) forecasts will reach over 50 billion gallons per year by 2017. Ethanol is not expected to be able to displace any of this diesel fuel, and biodiesel will be able to displace at most 2 billion gallons per year. Depending on the level of government support, use of domestic natural gas to power the nation's trucks and buses could displace 3, 5, 7 or over 10 billion gallons per year by 2017.

There are over 5 million NGVs on the road worldwide. Argentina is the world's leader with over 1.5 million NGVs (20 percent of all Argentine vehicles). According to the U.S. Energy Information Administration, the U.S. has only about 130,000 NGVs on the road in 2006. The number of diesel fueled vehicles that must switch to natural gas in order to achieve the above scenarios is modest – ranging from just 808,000 for 3 billion gallon of displacement to 2,756,000 for the 10 billion gallon displacement. The 10 billion-plus gasoline-gallon-equivalent shown in the scenario above would represent only 6.2 percent of the natural gas consumed in the U.S. in 2006. Using EIA's forecast, it would represent only 5.2 percent of the natural gas consumed in the U.S. in 2017 (82).

Finally, in the longer term, natural gas may be obtained from methane hydrates (82). Methane hydrates are ice formations consisting of methane and water. They can be found in Arctic areas and in the ocean floor at water depths greater than 1,000 feet. Methane hydrates are found throughout the world – including off all U.S. coasts. The U.S. Geological Survey conservatively estimates that energy contained in the world's methane hydrates is twice the energy contained in

all known fossil fuels on earth, i.e., twice that in all the world's estimated natural gas, petroleum and coal combined. Research is being carried out today to determine how to produce methane from hydrates economically. Officials in Japan, for example, have indicated that that country plans to have the technology needed to turn methane hydrates into commercial gas by 2016.

**Timeline:** Both propane and natural gas are available in the country. However propane's lower efficiency and the need for compressed storage of natural gas on-board the vehicle make them inconvenient personal vehicle fuel choices. However home refueling units such as the one shown above could allow more individuals to choose natural gas for fuel.

Until an area develops an adequate natural gas fueling station infrastructure (as has already developed in Southern California), NGVs are most practical for fleets.

**Costs:** The latest Alternative Fuel Price Report show the price of propane per gallon is less than regular gasoline. (76)

Compressed natural gas is the least expensive alternative fuel (except electricity) when you compare equal amounts of fuel energy. (77)

Southern California Gas estimates CNG currently costs about 40 percent less than gasoline (81). As of July 2005, PG&E charges approximately \$1.40 per therm, equivalent to about \$1.78 per gasoline gallon, for CNG used as a motor fuel.

### 5.3.2 Biogas

**Description and Features:** Biogas is the gaseous product of the anaerobic digestion (decomposition without oxygen) of organic matter. It is a mixture of methane, carbon dioxide, and traces of gases such as hydrogen, carbon monoxide, and nitrogen. Advantages of biogas as an alternative fuel include (78):

- Domestic, renewable resource
- Directly reduces greenhouse gas emissions by preventing methane release into the atmosphere.
- Anaerobic digestion systems (non-landfill) treat waste naturally, require less land area than aerobic composting, reduce the amount of material that must be land filled, reduce waste odors, and produce sanitized compost and nutrient-rich liquid fertilizer.

Biogas is produced naturally in landfills, and from the processing of animal waste, sewage, crop waste, and cellulosic and non-cellulosic crops. Biomethane is a pipeline-quality natural gas-substitute produced by purifying biogas. Landfills, animal waste "lagoons," and sewage processing plants are major sources of biogas, a major component of which is methane. A U.S. Department of Energy study concluded that a feasible biomethane potential from these sources is 10 billion gasoline-gallon-equivalents per year.

As a CO<sub>2</sub>-neutral source of energy it will be increasingly used to meet the Kyoto Protocol commitments and to benefit from the CO<sub>2</sub>-emission trade. Biogas is a flexible form of renewable energy that can produce heat, electricity and serve as a vehicle fuel.

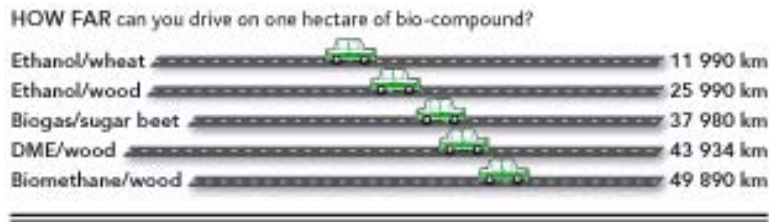
When used as automotive fuel, biogas is cleaned to a level of 97% methane. One cubic meter clean biogas is approximately the same as one litre gasoline. Biogas is the most environmentally friendly automotive fuel commercially available today. A person driving 15 000 kilometers per year contributes to a reduction of fossil carbon dioxide of 3600 kg per year (83).



Sweden and Switzerland are the only countries where pure biogas is available as transport fuel. The utilization of biogas as vehicle fuel uses the same engine and vehicle configuration as natural gas. Worldwide there are more than 3 million natural gas vehicles and about 10,000 biogas driven cars and buses, demonstrating that the vehicle configuration is not a problem for use of biogas as vehicle fuel. However, the gas quality demands are strict so the raw biogas from a digester or a landfill has to be upgraded (84).

**Timeline:** A 2007 (79, 80) report estimated that 12,000 vehicles are being fueled with upgraded biogas worldwide, with 70,000 biogas-fueled vehicles predicted by 2010. Europe has most of these vehicles. Sweden alone reports that more than half of the gas used in its 11,500 natural gas vehicles is biogas. Germany and Austria have established targets of 20% biogas in natural gas vehicle fuel.

In the United States, biogas vehicle activities have been on a smaller scale. Examples include a landfill in Whittier, California, that fuels vehicles with CNG derived from the landfill and an Orange County, California, landfill that produces LNG for use in transit buses (78).



Source: <http://www.businessregiongoteborg.com/huvudmeny/clusters/businessenvironment/biogaswest/>

**Challenges/Drawbacks:** Research and development are focusing on reducing the costs of biogas production and purification, producing higher-quality natural gas from biogas, and evaluating the performance of biogas-fueled vehicles.

### 5.3.3 Bio-diesel and Ethanol

**Description and Features:** Ethanol ( $\text{CH}_3\text{CH}_2\text{OH}$ ) is a renewable transportation fuel primarily made from starch crops, such as corn. It is also made from sugar beets and cane or cellulosic materials, such as fast-growing trees and grasses. Nearly one-third of U.S. gasoline contains ethanol in a low-level blend to reduce air pollution. (85, 86)

Ethanol is:

1. Produced from domestic crops, increasing Energy Security.
2. Fueling the Economy. Ethanol production is a new industry that is creating jobs in rural areas where employment opportunities are strongly needed.
3. Reduces Greenhouse Gas

Biodiesel is a liquid fuel made up of fatty acid alkyl esters, fatty acid methyl esters (FAME), or long-chain mono alkyl esters. It is produced from a variety of natural crops including rapeseed, soybean, mustard, flax, sunflower, canola, palm oil, hemp, jatropha and waste vegetable oils (87, 88). This fuel source is

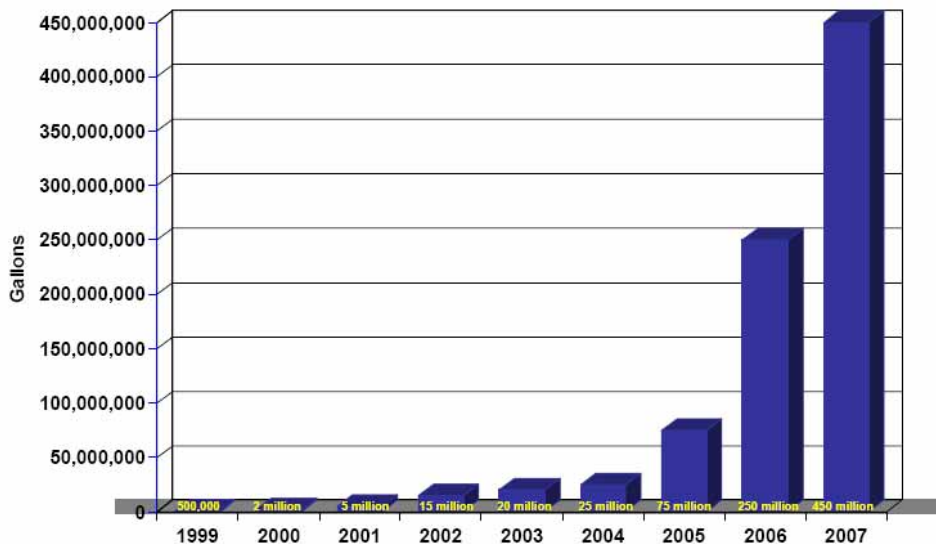
1. Clean-burning;
2. Domestically produced, Renewable substitute for petroleum diesel;
3. Nontoxic and biodegradable;
4. Capable of reducing engine wear.

Moreover, biodiesel has a positive energy balance. For every unit of energy needed to produce a gallon of biodiesel, 3.24 units of energy are gained. (89)

Since 2001, ethanol production has quadrupled from 1.6 billion gallons in 2000 to an estimated 6.4 billion gallons in 2007, with the vast majority coming from corn. In 2005, the United States became the world's leading ethanol producer, and last year, the U.S. accounted for nearly half of worldwide ethanol production. (90)

Last year, the U.S. produced about 450 million gallons of biodiesel – up 80 percent from 2006. Today, there are more than 650 biodiesel fueling stations, and hundreds of fleet operators use biodiesel to fuel their trucks. (90)

## Estimated US Biodiesel Production by Fiscal Year



Source: [http://www.biodiesel.org/pdf\\_files/fuelfactsheets/Production\\_Graph\\_Slide.pdf](http://www.biodiesel.org/pdf_files/fuelfactsheets/Production_Graph_Slide.pdf)

The US Energy Independence and Security Act of 2007 (EISA) mandates, among its many components, an aggressive ramp-up in the use of renewable fuels, culminating in a 36 billion gallon renewable fuel standard (RFS) by 2022. Of that, corn ethanol production is capped at 15 billion gallons per year starting in 2015; the remainder is expected to be provided by "advanced biofuels", the majority of which are cellulosic biofuels. (91)

Renewable Energy’s Office of Vehicle Technologies is funding efforts on two paths to increase ethanol consumption (91):

- Path A is to saturate the E10 markets and to significantly expand E85 markets at a greatly accelerated pace relative to today through the optimization of E85 use. The current E85 pathway won’t deliver the consumption result—there are too few vehicles, and not enough fueling stations.
- Path B is to verify intermediate blends of gasoline to use up to 15% or 20% ethanol (E15, E20) and to let market forces drive supply distribution. Currently, the EPA does not register any ethanol fuel blend above E10 or below E85.

Biofuels has also emerged as an important alternative fuel in the European Union. However, recently the plans have been scaled down due to increasing concerns regarding food security (92).

**Costs:** E85 (85% ethanol, 15% gasoline) typically costs about the same or slightly less than gasoline on a gallon-for-gallon basis (85). The cost of Biodiesel is competitive with diesel. (89)

When evaluating the total costs associated with other alternative fuel systems, many fleet managers have determined biodiesel is their least-cost strategy to comply with state and federal regulations. Use of biodiesel does not require major engine modifications. That means operators keep their fleets, their spare parts inventories, their refueling stations, and their skilled mechanics. (93)

America’s biodiesel industry will add \$24 billion to the U.S. economy between 2005 and 2015, assuming biodiesel growth reaches 650 million gallons of annual production by 2015. Biodiesel production will create a projected 39,102 new jobs in all sectors of the economy. It will keep \$13.6 billion in America that would otherwise be spent on foreign oil (94).

**Table 1. Overall Average Fuel Prices**

	<i>Nationwide Average Price for Fuel This Report</i>	<i>Nationwide Average Price for Fuel Last Report</i>	<i>Change in Price This Report vs. Last Report</i>	<i>Units of Measurement</i>
Gasoline (Regular)	\$2.76	\$3.03	(\$0.27)	per gallon
Diesel	\$3.11	\$2.96	\$0.15	per gallon
CNG	\$1.77	\$2.09	(\$0.32)	per GGE
Ethanol (E85)	\$2.40	\$2.63	(\$0.23)	per gallon
Propane	\$2.75	\$2.58	\$0.17	per gallon
Biodiesel (B20)	\$3.08	\$2.96	\$0.12	per gallon
Biodiesel (B2-B5)	\$2.99	\$2.84	\$0.15	per gallon
Biodiesel (B99-B100)	\$3.38	\$3.27	\$0.11	per gallon

**Table 2. October 2007 Overall Average Fuel Prices on Energy-Equivalent Basis**

	<i>Nationwide Average Price in Gasoline Gallon Equivalents</i>	<i>Nationwide Average Price in Diesel Gallon Equivalents</i>	<i>Nationwide Average Price in Dollars per Million Btu</i>
Gasoline	\$2.76	\$3.08	\$23.95
Diesel	\$2.79	\$3.11	\$24.13
CNG	\$1.77	\$1.98	\$15.37
Ethanol (E85)	\$3.39	\$3.78	\$29.40
Propane	\$3.80	\$4.23	\$32.90
Biodiesel (B20)	\$2.81	\$3.14	\$24.39
Biodiesel (B2-B5)	\$2.68	\$2.99	\$23.26
Biodiesel (B99-B100)	\$3.33	\$3.72	\$28.87

Source: [http://www.eere.energy.gov/afdc/pdfs/afpr\\_oct\\_07.pdf](http://www.eere.energy.gov/afdc/pdfs/afpr_oct_07.pdf)

**Transportation Applications:** E85 (85% ethanol, 15% gasoline) is considered an alternative fuel. It is used to fuel E85-capable flexible fuel vehicles (FFVs), which are available in a variety of models from U.S. and foreign automakers. (85)

At the production level, biodiesel fuel is a clean and affordable fuel for trucks, buses, farm equipment and other forms of heavy transportation (87). Biodiesel can be used in conventional diesel engines, directly substituting for or extending supplies of traditional petroleum diesel (95). Modern diesel engine technology has taken the advantages of biofuel usage.

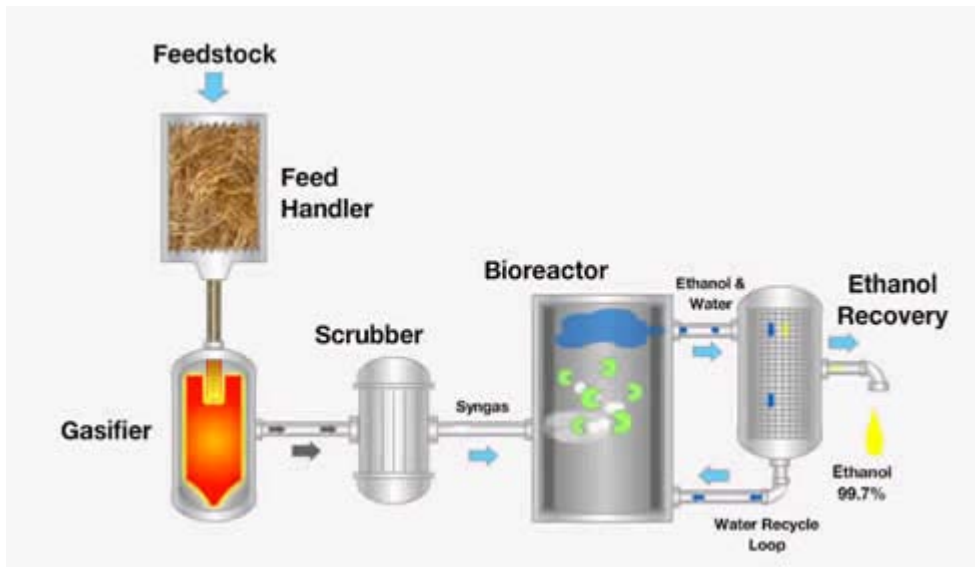
**Challenges/Drawbacks:** It is generally opined that ethanol requires more energy to produce than what it provides. However, recent study by Argonne National Laboratory (a U.S. Department of Energy Laboratory), indicates a 38% gain in the overall energy input/output equation for the corn-to-ethanol process. (95)

However import of biofuels can have negative social impacts since it increases the cost of food in places such as Mexico by re-directing corn produce for fuel production (96).

Biodiesel is not currently widely available, even though there production-scale plants, such as NOPEC, do exist (91). Biodiesel (B100) has about 8 percent less energy per gallon than petroleum diesel, so more gallons of biodiesel are needed to power a vehicle than a comparable volume of petroleum diesel (97). E85 has about 27% less energy per gallon than gasoline.

**Implementation or Commercial Examples:** By 2012, 50 percent of GM cars will be "Flex Fuel" models that run on up to 85 percent ethanol, because that fuel source has the most potential in the short term (98).

Coskata, Inc. is a biology-based renewable energy company, with technology for the production of liquid fuels. Using proprietary microorganisms and transformative bioreactor designs, the company will produce ethanol for under US\$1.00 per gallon anywhere in the world, from almost any input material (feedstock).



Source: Coskata Inc.

### 5.3.4 Electric-driven and Hybrid vehicles

**Description and Features:** Electricity used to power vehicles is generally provided by the electricity grid and stored in the vehicle's batteries. There are no tailpipe emissions. But the emissions can be generated in the electricity production process. There are concerns whether this could lead to overall increase in pollution (131).

Multiple technologies feed into developing hybrid vehicles including: Electric propulsion systems, Electrical energy storage systems (e.g., batteries, power capacitors), on-board data acquisition and control system. While several hybrid vehicles are available in passenger vehicle market, research is on-going to adopt hybrid technology for heavy-vehicles (99).

**Timeline:** The world hybrid-vehicle market, estimated at 384,000 vehicles in 2006, is projected to reach 1.1 million units in 2010 and 2 million units by 2015 (100).

Despite rapid growth in hybrid-electric vehicle sales forecasted over the next few years, hybrid market share is expected to top out at 3 percent of the U.S. automotive market by 2010, according to the J.D. Power-LMC Automotive Forecasting Services Hybrid-Electric Vehicle Outlook (101).

**Costs:** Electricity fueling costs for electric vehicles are reasonable compared to gasoline. \$0.05 per mile for vehicles with direct current (DC) electric systems and \$0.03 cents per mile for vehicles with alternating current (AC) systems.

**Transportation Applications:** Electricity can be used to power electric and plug-in hybrid electric vehicles directly from the power grid (102). Hybrid Electric Vehicles (HEVs) are becoming widely available for a variety of applications (103, 104).

**Challenges/Drawbacks:** Several barriers are preventing widespread commercialization of plug-in hybrid electric vehicles (PHEVs), including the following:



1. Hybrid component mass, volume, cost, reliability, and safety
2. Lack of domestic sources for batteries
3. Consumer behavior and expectations
4. Robust operation in range of environmental conditions.
5. Cost of battery
6. Energy storage density / vehicle range,
7. Refueling facility (for pure electric vehicles) (105)

**Implementation or Commercial Examples:** Research efforts include DoE's FreedomCAR and Vehicle Technologies (FCVT) Program evaluating PHEV (106, 107), National Renewable Energy Laboratory's Advanced Vehicle and Fuels research program on HEV (108). Commercial players including Toyota (109), Honda (110), Ford (111), General Motors (112) are developing PHEV. The Ann Arbor Transportation Authority is operating several Hybrid buses (113). Cadillac Provoq, which runs on Lithium-Ion batteries and hydrogen fuel cells and GMs Volt are expected to be in the market within the next 5 years.

GMs volt has a very powerful all-electric 161-horsepower 45KW (53 KW peak) motor that is the only engine to power the car at all times. This engine should be capable of moving the car from 0 to 60 in 8.5 seconds, and have a top speed of at least 100 mph. Another very important feature of the Volt is that it will still have an on-board gasoline/E85 combustion engine. This engine is the smaller one, and has only one task, it charges the battery pack when the stored power gets low. The motor is not connected to the wheels, it is only a generator. The brilliance of this feature is that you will have an overall driving range of 600-700 miles, greater than most gas cars now. The efficiency of this motor amounts to about 50mpg, for each gallon you use to charge the batteries.



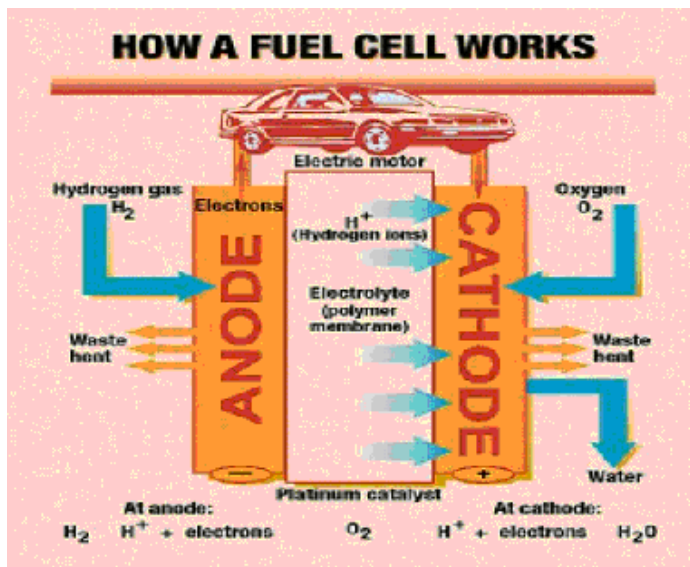
### 5.3.5 Hydrogen Fuel

**Description and Features:**

Hydrogen fuel is

1. Clean-burning;
2. High potential for domestic production;
3. A fuel with high efficiency. The energy in 2.2 lb (1 kg) of hydrogen gas is about the same as the energy in 1 gallon of gasoline. (114, 115)

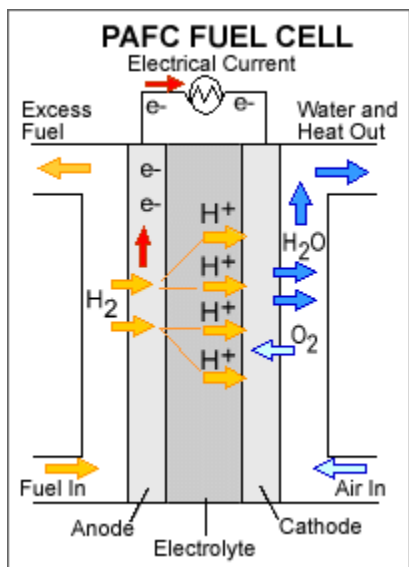
Hydrogen can be produced using diverse, domestic resources including nuclear; natural gas and coal; and biomass and other renewable including solar, wind, hydroelectric, or geothermal energy. This diversity of domestic energy sources makes hydrogen a promising energy carrier and important to our nation's energy security. It is expected and desirable for hydrogen to be produced using a variety of resources and process technologies (or pathways). DOE focuses on



hydrogen production technologies that result in near-zero net greenhouse gas emissions and use renewable energy sources, nuclear energy, and coal (when combined with carbon sequestration). To ensure sufficient clean energy for our overall energy needs, energy efficiency is also important. Hydrogen can be produced via various process technologies, including thermal (natural gas reforming, renewable liquid and bio-oil processing, and biomass and coal gasification), electrolytic (water splitting using a variety of energy resources), and photolytic (splitting water using sunlight via biological and electrochemical materials). Hydrogen can be produced in large, central facilities (50-300 miles from point of use), smaller semi-central (located within 25-100 miles of use) and distributed (near or at point of use). In order for hydrogen to be successful in the market place, it must be cost competitive with the available alternatives. In the light duty vehicle transportation market, this means that hydrogen needs to be available at \$2-\$3/gge (untaxed). This would result in hydrogen fuel cell vehicles having the same cost to the consumer on a cost per mile driven basis as a comparable conventional internal combustion engine or hybrid vehicle. DOE is engaged in research and development of a variety of hydrogen production technologies. Some are further along in development than others — some can be cost competitive for the transition period (beginning in 2015), while others are considered long-term technologies (cost-competitive after 2030) (116).

The major conclusions from a recent study (117) on Hydrogen fuel are:

- Greenhouse gas reductions: the hydrogen-powered fuel cell vehicle is the only option that can achieve the goal of reducing GHGs by 60% or more below 1990 levels in the transportation sector; the second-best option, cellulosic ethanol PHEVs, could at best achieve a 20% reduction, and even then not until 2090.
- Urban air pollution: the hydrogen-powered fuel cell vehicle is the only option that would virtually eliminate urban air pollution from the transportation sector by 2100; all other vehicle/fuel options including both gasoline and ethanol PHEVs would produce essentially the same or greater urban air pollution as the existing car fleet due to increased vehicle miles traveled.



- Petroleum consumption: the hydrogen-powered fuel cell vehicle is the only option that could achieve energy "quasi-independence" reaching that milestone by mid-century; the second-best option, ethanol PHEVs would still consume over 5 million barrels oil per day by the end of the century.
- Societal cost savings: hydrogen-powered fuel cell vehicles will provide greater societal cost savings than any other alternative: each FCV sold will cut societal costs by a factor of 7.6 relative to conventional gasoline cars in the near-term (now to 2020), by a factor of 9.5 in the mid-term (2021 to 2050) and by a factor of 15.5 in the long-term (2051 to 2100); second-best option is the hydrogen-powered ICE HEV (reduction factors of 5.0, 6.2, 11.7); third-best the battery EV (4.2, 4.6, 10.6); fourth-best the ethanol plug-in hybrid (3.8, 4.8, 6.8) and fifth-best the gasoline plug-in hybrid (1.7, 2.1, 2.9).

Phosphoric Acid Fuel Cells (PAFC) use liquid phosphoric acid as an electrolyte—the acid is contained in a Teflon-bonded silicon carbide matrix—and porous carbon electrodes containing a platinum catalyst. The chemical reactions that take place in the cell are shown in the diagram to

the right. The phosphoric acid fuel cell (PAFC) is considered the "first generation" of modern fuel cells. It is one of the most mature cell types and the first to be used commercially, with over 200 units currently in use. This type of fuel cell is typically used for stationary power generation, but some PAFCs have been used to power large vehicles such as city buses.

PAFCs are more tolerant of impurities in fossil fuels that have been reformed into hydrogen than Polymer Electrolyte Membrane (PEM) cells, which are easily "poisoned" by carbon monoxide—carbon monoxide binds to the platinum catalyst at the anode, decreasing the fuel cell's efficiency. They are 85 percent efficient when used for the co-generation of electricity and heat, but less efficient at generating electricity alone (37 to 42 percent). This is only slightly more efficient than combustion-based power plants, which typically operate at 33 to 35 percent efficiency. PAFCs are also less powerful than other fuel cells, given the same weight and volume. As a result, these fuel cells are typically large and heavy. PAFCs are also expensive. Like PEM fuel cells, PAFCs require an expensive platinum catalyst, which raises the cost of the fuel cell (118).

**Timeline:** Ford currently has a fleet of 30 hydrogen-powered Focus fuel cell vehicles on the road as part of a worldwide, seven-city program to conduct real-world testing of fuel cell technology. The fleet has accumulated more than 300,000 miles since its inception. (119)

**Costs:** Hydrogen is currently very expensive because it's difficult to generate, handle, and store (7). This total cost is \$3.0 to \$7.4/kg of H<sub>2</sub>, or \$1.12 to \$3.20/gallon of displaced gasoline/diesel, which compares with the actual costs of U.S. gasoline and diesel in mid-March 2005 of \$2.06 and \$2.19, respectively. Adding the reduction in health and mortality costs from wind HFCVs of \$0.29 to \$1.80/gallon, which is the externality cost of gasoline, gives a direct cost plus externality cost of U.S. gasoline/diesel of \$2.35 to \$3.99/gallon, which exceeds the mean cost of hydrogen from wind (\$2.16/gallon) even if retail hydrogen is marked up. (120)

The cost of fuel cell stacks has decreased tenfold in just three years. GM's latest fuel cell concept vehicle, the Sequel, has a lower-cost fuel cell stack than the earlier Hy-wire concept vehicle. But the price is still too high to make a vehicle that costs the same as today's vehicles. (121)

Today, compressed hydrogen can be shipped in tube trailers at pressures up to 3,000 psi (about 200 bar). This method is expensive, however, and it is cost-prohibitive for distances greater than about 200 miles. Researchers are investigating technology that might permit tube trailers to operate at higher pressures (up to 10,000 psi), which would reduce costs and extend the utility of this delivery option. (118)

Using today's technology, liquefaction consumes more than 30% of the energy content of the hydrogen and is expensive. In addition, some amount of stored hydrogen will be lost through evaporation, or "boil off" of liquefied hydrogen, especially when using small tanks with large surface-to-volume ratios. Research to improve liquefaction technology, as well as improved economies of scale, could help lower costs (today's liquefaction units are small to meet minimal demand). (118)

A typical phosphoric acid fuel cell costs between \$4,000 and \$4,500 per kilowatt to operate. (118)

Based on a 2001 survey of leading stationary fuel cell manufacturers, the installed cost of fuel cells is expected to fall from an average of \$4,500/kW in 2002 to about \$1,000/kW by 2010. This price drop is associated with an expected increase in sales, subsequent adoption of mass production, and discounts for large orders. (122)

**Transportation Applications:** Fuel cell vehicles, powered by Hydrogen, have the potential to revolutionize our transportation system. They are more efficient than conventional internal combustion engine vehicles and produce no harmful tailpipe exhaust—their only emission is water. (123)

BMW Hydrogen 7 powered by liquid hydrogen and gasoline bi-fuel vehicle is an industrial application case in USA (124). Hydrogen Fuel Cell Bicycles developed in China (125). Hydrogen is currently available only as an industrial or scientific chemical product, not as a bulk fuel. (126)

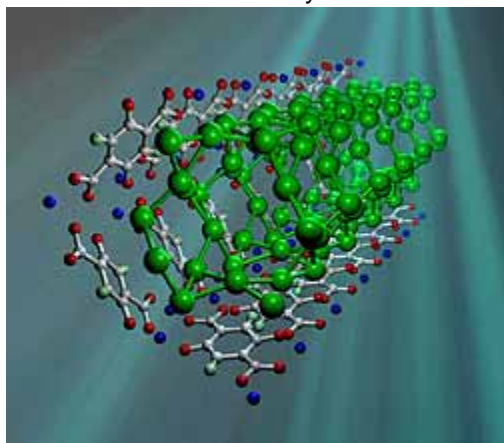
Hydrogen Hybrid-Electric Vehicle: A hybrid-electric vehicle avoids the currently high cost of fuel cells while achieving high fuel efficiency. The equivalent energy efficiency is 80-mpg, with a range of 300 miles. It would require onboard storage of 3.75 kg, which could be increased to provide a longer driving range.

Fuel Cell Electric Vehicle: A fuel cell effective vehicle would be three times as efficient as the current internal combustion engine. The vehicle would achieve the equivalent of 90-mpg and have equal fuel costs at a hydrogen cost of \$3.75 per gallon, or \$30/GJ. When fuel cells become less costly, they would become the ideal choice for hydrogen-powered vehicles. (127)

Ford Edge with HySeries Drive™ is the world's first drivable fuel cell hybrid electric plug-in that combines an onboard hydrogen fuel cell generator with lithium-ion batteries to deliver more than 41 mpg with zero emissions.

The plug-in hybrid is powered by a 336-volt lithium-ion battery pack at all times. The vehicle drives the first 25 miles each day on stored electricity alone, after which the fuel cell begins operating to keep the battery pack charged. This provides another 200 miles of range for a total of 225 miles with zero emissions. (119)

Wind hydrogen fuel cell vehicles (HFCV) may save 2300 to 4000 lives/year and \$32 billion to \$180 billion/year in the United States relative to hybrids, and that wind or natural gas HFCVs may save 3700 to 6400 lives/year and reduce asthma by 1 million to 3 million cases/year relative to current fossil-fuel onroad vehicles. Because wind HFCVs result in the greatest health-plus-climate benefit among all cases, examining the cost to the U.S. economy of producing hydrogen from wind is warranted.



Source: NIST

**Challenges/Drawbacks:**

1. Storage Technologies. Hydrogen has a low volumetric energy density. Therefore, to store the same amount of energy, hydrogen needs larger storage tank than gasoline. (114, 115, 128)
2. The primary challenge for hydrogen production is reducing the cost of production technologies to make the resulting hydrogen cost competitive with conventional transportation fuels. (114, 115)

One of the key engineering challenges to building a clean, efficient, hydrogen-powered car is how to design the fuel tank. Storing enough raw hydrogen for a reasonable driving range would require either impractically high pressures for gaseous hydrogen or extremely low temperatures for liquid hydrogen. In a new paper\* researchers at the National Institute of Standards and

Technology's Center for Neutron Research (NCNR) have demonstrated that a novel class of materials could enable a practical hydrogen fuel tank.

MOF-74 resembles a series of tightly packed straws comprised mostly of carbon atoms (white balls) with columns of zinc ions (blue balls) running down the walls. Heavy hydrogen molecules (green balls) adsorbed in MOF-74 pack into the tubes more densely than they would in solid form.

**Implementation or Commercial Examples:**

Nissan aims to introduce a new fuel-cell vehicle using an improved fuel stack developed in-house after 2010 that will offer performance on par with gasoline-power automobiles. (129)

The Chevy Equinox Fuel Cell contains General Motor's fourth generation fuel cell propulsion system including a 93 kw fuel cell, 73 kw front-wheel drive 3-phase asynchronous electric motor and 35 kw nickel metal hydride battery pack. The Equinox Fuel Cell uses 3 carbon fiber fuel tanks, pressurized to 10,000 psi and has a range of 200 miles before refueling. With a top speed of 100 mph, the Chevrolet Equinox Fuel Cell accelerates from 0 - 60 mph in 12 seconds. The 5-door, 4-seat vehicle is expected to meet all 2007 U.S. Federal Motor Vehicle Safety Standards. (130)

## 6 Description of Database

The database allows easy access to the information and allows the user to organize the information in convenient formats. The details for each technology include: features, timeline, costs, applications to transportation, and challenges. The features field describes

A COMPREHENSIVE SURVEY OF EMERGING TECHNOLOGY FOR NEW YORK METROPOLITAN AREA

Technology Database - Main Form

This database is part of the "Comprehensive Survey of Emerging Technology for New York Metropolitan Area" project. The database has a list of technologies, its details, as well as its rating with respect to different policy objectives. You could search the database for technologies based on your criteria or pick a technology and request additional details about the technology.

What would you like to do?

I want to search for technologies that meet my criteria.

I want to find details about a technology.



A COMPREHENSIVE SURVEY OF EMERGING TECHNOLOGY FOR NEW YORK METROPOLITAN AREA



Technology Database - Main Form

Select a category followed by specific criteria. For example if you want to search for "Congestion Reduction and Management" technologies that have a high rating for "highway system improvement" criterion, select "Congestion Reduction and Management" as the policy, and "highway system improvement" as the criterion in the first line, then under relationship select ">=" and under rating choose the maximum rating of "5". You can also search for multiple (upto 5) criteria and couple the criteria based on "AND" or "OR" logical operators.

Please select policy category:

Criteria	Relationship	Rating
<input type="text" value="Highway_system_improvements"/>	<input "="" type="text" value="&gt;="/>	<input type="text" value="4"/>
<input type="text" value="OR"/>		
<input type="text" value="Transit_system_improvements"/>	<input type="text" value="&gt;"/>	<input type="text" value="3"/>
<input type="text" value="OR"/>		
<input type="text" value="Intelligent_transportation_systems"/>	<input type="text" value="&gt;"/>	<input type="text" value="4"/>
<input type="text" value="OR"/>		
<input type="text" value="Transportation_demand_management_strategies"/>	<input type="text" value="&gt;"/>	<input type="text" value="4"/>
<input type="text" value=""/>		
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the technology in detail including the components and capabilities of the technology. The timeline provides a subjective estimate of the level of maturity of the technology and the time to implementation. Costs provide estimates of the implementation and operational cost and economic benefits from the technology. Given the uncertainty involved and the fact that these technologies are still under development, in most cases the costs are rough estimates. The next field identifies the potential application of the technology to transportation domain. What are the different benefits arising from the technology in terms of congestion reduction and management, air quality improvement, safety and security etc. is also discussed in the database. Finally, the field corresponding to 'challenges' lists the main hurdles to the development of the technology. In addition to these details the

database has additional information with regard to how effective the technology is towards meeting specific policies or goals. This is a rating carried out as part of task 4 in order to short-list the technologies. The figures below demonstrate screenshots of the user-friendly forms available in the database.

A COMPREHENSIVE SURVEY OF EMERGING TECHNOLOGY FOR NEW YORK METROPOLITAN AREA

Technology Database

Two separate reports are available for each technology. The "ratings" report lists the rating of the technology for the different criteria. The "details" report provides additional information about the technology.

Select the technology and select the report you want to view. You can select multiple (upto 5) technologies.

Technology 1: Nanosensors

Technology 2: Ethanol Fuel

Technology 3: Natural gas

Technology 4: DSRC

Technology 5: Advanced route guidance systems

Get Ratings      Get Details

## 7 Reference:

1. <http://www.sirf.com/sirfamplifyingLBS.pdf>
2. <http://www.travelsurveymethods.org/pdfs/RESEARCH%20NEEDS%20STATEMENTS%20ABJ40%20August%202007.pdf>
3. Rehr, K. Brunsch, S. Mentz, H.-J. and Salzburg Res., "Assisting Multimodal Travelers: Design and Prototypical Implementation of a Personal Travel Companion", IEEE Transactions on Intelligent Transportation Systems, Vol 8(1), 2007.
4. Rafferty, P., Treasize, M., Wisconsin Ramp Metering Operations and Implementation. <http://www.ctre.iastate.edu/pubs/midcon2007/RaffertyMetering.pdf>
5. [http://www.calccit.org/itsdecision/serv\\_and\\_tech/Ramp\\_metering/ramp\\_metering\\_summary.html](http://www.calccit.org/itsdecision/serv_and_tech/Ramp_metering/ramp_metering_summary.html)
6. L Chu, HX Liu, W Recker, HM Zhang, Performance Evaluation of Adaptive Ramp-Metering Algorithms Using Microscopic Traffic Simulation, Journal of Transportation Engineering, 2004.
7. Konstantinos Markantonakis, Keith Mayes, "Smart Card Technology in the Public Transport Industry", *Secure Magazine - The Silicon Trust Report, February 2004, Issue 1/2004*, pp 26-29. <http://www.scc.rhul.ac.uk/public/smart%20card%20centre+omnikey.pdf>
8. <http://www.smartcardalliance.org>

9. <http://www.mastercard.com/us/paypass/subway/index.html>
10. [http://www.smartcardalliance.org/download/pdf/Transit\\_Financial\\_Linkages\\_WP.pdf](http://www.smartcardalliance.org/download/pdf/Transit_Financial_Linkages_WP.pdf)
11. [http://www.smartcardalliance.org/download/pdf/Co-Branded\\_Multi-Application\\_Contactless\\_Cards\\_WP.pdf](http://www.smartcardalliance.org/download/pdf/Co-Branded_Multi-Application_Contactless_Cards_WP.pdf)
12. [http://economist.com/printedition/displaystory.cfm?story\\_id=9249278](http://economist.com/printedition/displaystory.cfm?story_id=9249278)
13. [http://travel.state.gov/passport/eppt/eppt\\_2502.html](http://travel.state.gov/passport/eppt/eppt_2502.html)
14. <http://www.computerworld.com/action/article.do?command=viewArticleBasic&articleId=9007622>
15. <http://www.smartcardalliance.org/pages/smart-cards-applications-transportation>
16. [http://www.smartcardalliance.org/download/pdf/Transit\\_Financial\\_Linkages\\_WP.pdf](http://www.smartcardalliance.org/download/pdf/Transit_Financial_Linkages_WP.pdf)
17. Fare Policies, Structures and Technologies: Update, TCRP Report No 94, 2003. [http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp\\_rpt\\_94.pdf](http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_94.pdf)
18. <http://faculty.washington.edu/jbs/itrans/PRT/Background.html>
19. Viability of Personal Rapid Transit in New Jersey, Feb 2007, <http://faculty.washington.edu/jbs/itrans/big/PRTfinalreport.pdf>
20. Personal Automated Transportation: Status and Potential of Personal Rapid Transit, January 2003 by the Advanced Transit Association <http://www.advancedtransit.org/pub/2002/prt/tech6.pdf>
21. <http://www.ultraprt.com/heathrow.htm>
22. Vehicle Safety Communications Project - Final Report, National Highway Traffic Safety Administration, April 2006. <http://www.nrd.nhtsa.dot.gov/pdf/nrd-12/060419-0843/PDFs/MainReport.pdf>
23. <http://www.clean-diesel.org/highway.html>
24. [http://www.standards.its.dot.gov/Documents/advisories/dsrc\\_advisory.htm](http://www.standards.its.dot.gov/Documents/advisories/dsrc_advisory.htm)
25. <http://www.rfidjournal.com/article/articleview/866/1/1/>
26. <http://www.itsa.org/itsa/files/pdf/DSRCICWhitePaper.pdf>
27. <http://www.reason.org/surfacetransportation18.shtml>
28. M. Zimmer, Surveillance, Privacy and the Ethics of Vehicle Safety Communication Technologies, *Ethics and Information Technology*, Vol. 7 No. 4, Dec 2005.
29. <http://www.eeng.dcu.ie/~whelanp/ivsi/IVSI.pdf>
30. [http://news.com.com/Computer+system+said+to+help+stop+drowning/2100-1041\\_3-5558015.html](http://news.com.com/Computer+system+said+to+help+stop+drowning/2100-1041_3-5558015.html)
31. [http://www.examiner.com/a-287274%7EU\\_Md\\_helping\\_to\\_fine\\_tune\\_advanced\\_fire\\_alert\\_system.html](http://www.examiner.com/a-287274%7EU_Md_helping_to_fine_tune_advanced_fire_alert_system.html)
32. <http://homepages.inf.ed.ac.uk/rbf/CVonline/applc.htm>
33. [http://www.gm.com/corporate/responsibility/safety/news/2007/eye\\_on\\_safety\\_110507.jsp](http://www.gm.com/corporate/responsibility/safety/news/2007/eye_on_safety_110507.jsp)
34. <http://www.bmva.ac.uk/apps/transport.html>
35. Masaki, I. 1998. Machine-Vision Systems for Intelligent Transportation Systems. *IEEE Intelligent Systems* 13, 6 (Nov. 1998), 24-31
36. Munder, S; Gavril, D M, An Experimental Study on Pedestrian Classification, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 28 No. 11
37. <http://www.cs.ubc.ca/spider/lowe/vision.html>
38. <http://www.memsnet.org/mems/what-is.html>
39. [http://www.st.com/stonline/products/families/sensors/motion\\_sensors.htm](http://www.st.com/stonline/products/families/sensors/motion_sensors.htm)
40. <http://members.forbes.com/asap/2001/0402/051.html>
41. The Future of MEMS in Transportation Infrastructure Systems, 2003 <http://onlinepubs.trb.org/onlinepubs/circulars/ec056.pdf>
42. [http://www.analog.com/Analog\\_Root/static/solutionsTab/solutions/automotive.html](http://www.analog.com/Analog_Root/static/solutionsTab/solutions/automotive.html)
43. <http://www.sensorsmag.com/sensors/Cars%2FTransportation/MEMS-Sensors-Are-Driving-the-Automotive-Industry/ArticleStandard/Article/detail/361648>

44. <http://www.popsci.com/popsci/automotivetech/86743bcc2eb84010vgnvcm1000004eecbccdrerd.html>
45. [http://www.calccit.org/itsdecision/serv\\_and\\_tech/Collision\\_avoidance/longitudinal.html](http://www.calccit.org/itsdecision/serv_and_tech/Collision_avoidance/longitudinal.html)
46. [http://www.calccit.org/itsdecision/serv\\_and\\_tech/Collision\\_avoidance/summary.htm](http://www.calccit.org/itsdecision/serv_and_tech/Collision_avoidance/summary.htm)
47. <http://www.its.dot.gov/ivi/ivi.htm>
48. <http://www.darpa.mil/grandchallenge/index.asp>
49. <http://www.cts.umn.edu/pdf/CTS-05-01.pdf>
50. <http://www.popsci.com/cars/article/2003-02/adaptive-cruise-control-meet-your-new-co-pilot>
51. <http://www.citroen.com/CWW/en-US/TECHNOLOGIES/SECURITY/AFIL/>
52. <http://onlinepubs.trb.org/onlinepubs/sr/sr253.html>
53. <http://www.libn.com/article.htm?articleID=35619>
54. <http://www.globalsources.com/gsol/l/Lane-departure/a/9000000091349.htm>
55. <http://www.sciencenews.org/articles/20041127/mathtrek.asp>
56. [http://www.usc.edu/dept/ee/catt/2002/margareta/surface/TO4217\\_final.pdf](http://www.usc.edu/dept/ee/catt/2002/margareta/surface/TO4217_final.pdf)
57. <http://www.its.dot.gov/ivi/ivihf/index.html>
58. [http://www.darpa.mil/grandchallenge/docs/Grand\\_Challenge\\_2005\\_Report\\_to\\_Congress.pdf](http://www.darpa.mil/grandchallenge/docs/Grand_Challenge_2005_Report_to_Congress.pdf)
59. de Luis-García, R., Alberola-López, C., Aghzout, O., and Ruiz-Alzola, J. 2003. Biometric identification systems. *Signal Process.* 83, 12 (Dec. 2003), 2539-2557
60. <http://www.technovelgy.com/ct/Technology-Article.asp?ArtNum=10>
61. <http://www.lgiris.com/index.php>
62. <http://ctl.ncsc.dni.us/biomet%20web/BMFingerprint.html>
63. <http://www.neurotechnologija.com/face-biometrics.html>
64. <http://ctl.ncsc.dni.us/biomet%20web/BMRetinal.html>
65. <http://www.technologyexecutivesclub.com/Articles/security/artRetinalRecognition2.php>
66. <http://blog.wired.com/gadgets/2007/10/i-see-you-new-p.html>
67. [http://et.wcu.edu/aidc/BioWebPages/Biometrics\\_Finger.html](http://et.wcu.edu/aidc/BioWebPages/Biometrics_Finger.html)
68. <http://albany.bizjournals.com/albany/stories/2007/07/30/daily36.html>
69. <http://www.opticsreport.com/content/printable.php?id=1014&command=article>
70. [http://www.eere.energy.gov/afdc/fuels/propane\\_what\\_is.html](http://www.eere.energy.gov/afdc/fuels/propane_what_is.html)
71. [http://www.propanecouncil.org/newsroom/press\\_releaseDetail.cfv?id=434](http://www.propanecouncil.org/newsroom/press_releaseDetail.cfv?id=434)
72. <http://www.socalgas.com/business/ngv/fleets.shtml>
73. <http://www.nrel.gov/docs/fy07osti/41884.pdf>
74. [http://www.eere.energy.gov/afdc/fuels/natural\\_gas.html](http://www.eere.energy.gov/afdc/fuels/natural_gas.html)
75. [http://www.eere.energy.gov/afdc/vehicles/natural\\_gas\\_what\\_is.html](http://www.eere.energy.gov/afdc/vehicles/natural_gas_what_is.html)
76. [http://www.eere.energy.gov/afdc/price\\_report.html](http://www.eere.energy.gov/afdc/price_report.html)
77. <http://www.altfuels.org/backgrnd/altftype/cng.html>
78. [http://www.eere.energy.gov/afdc/fuels/emerging\\_biogas\\_what\\_is.html](http://www.eere.energy.gov/afdc/fuels/emerging_biogas_what_is.html)
79. <http://www.iea-biogas.net/Dokumente/Brochure%20final.pdf>
80. <http://webserv5.sdu.dk/bio/Probiogas/down/work07/Proceedings.pdf>
81. <http://www.consumerenergycenter.org/transportation/afvs/cng.html>
82. <http://www.ngvc.org/pdfs/PotentialNGVs.pdf>
83. [http://www.svenskbiogas.se/sb/docs/english/Engelsk\\_folder.pdf](http://www.svenskbiogas.se/sb/docs/english/Engelsk_folder.pdf)
84. <http://www.iea-biogas.net/Dokumente/Brochure%20final.pdf>
85. [http://www.eere.energy.gov/afdc/fuels/ethanol\\_what\\_is.html](http://www.eere.energy.gov/afdc/fuels/ethanol_what_is.html)
86. <http://freeenergynews.com/Directory/Ethanol/>
87. <http://www.eere.energy.gov/afdc/fuels/biodiesel.html>
88. <http://www.alternative-energy-news.info/technology/biofuels/biodiesel-fuel/>
89. [http://www.biodiesel.org/pdf\\_files/fuelfactsheets/Benefits%20of%20Biodiesel.Pdf](http://www.biodiesel.org/pdf_files/fuelfactsheets/Benefits%20of%20Biodiesel.Pdf)
90. <http://www.whitehouse.gov/infocus/energy/>
91. <http://www.greencarcongress.com/2008/02/figuring-out-ho.html#more>

92. <http://www.euractiv.com/en/energy/biofuels-generation/article-165951>
93. <http://www.consumerenergycenter.org/transportation/afvs/biodiesel.html>
94. [http://www.biodiesel.org/pdf\\_files/fuefactsheets/EconomicImpactLECG2006.pdf](http://www.biodiesel.org/pdf_files/fuefactsheets/EconomicImpactLECG2006.pdf)
95. <http://www.ncga.com/ethanol/pdfs/Wang2005.pdf>
96. [http://www.cleanfuelsdc.org/pubs/documents/04CFDC-003\\_IssueBrief.pdf](http://www.cleanfuelsdc.org/pubs/documents/04CFDC-003_IssueBrief.pdf)
97. <http://www.ngvc.org/pdfs/35BilGalWhtPaper.pdf>
98. <http://blog.wired.com/gadgets/2008/01/ces-keynote-gen.html>
99. Advanced heavy hybrid propulsion systems,  
<http://www.nrel.gov/vehiclesandfuels/ahhps/>
100. <http://www.evworld.com/news.cfm?newsid=14976>
101. <http://www.jdpower.com/corporate/news/releases/pressrelease.aspx?ID=2005013>
102. [http://www.eere.energy.gov/afdc/vehicles/plugin\\_hybrids.html](http://www.eere.energy.gov/afdc/vehicles/plugin_hybrids.html)
103. [http://www.eere.energy.gov/afdc/vehicles/hybrid\\_electric.html](http://www.eere.energy.gov/afdc/vehicles/hybrid_electric.html)
104. <http://www.nrel.gov/vehiclesandfuels/hev/hevs.html>
105. [http://www.worldenergy.org/documents/transportation\\_study\\_final\\_online.pdf](http://www.worldenergy.org/documents/transportation_study_final_online.pdf)
106. <http://www.transportation.anl.gov/pdfs/HV/376.pdf>
107. <http://www1.eere.energy.gov/vehiclesandfuels/technologies/systems/index.html>
108. <http://www.nrel.gov/vehiclesandfuels/hev/>
109. [http://www.toyota.com/vehicles/minisite/hsd/index.html?s\\_van=GM\\_TN\\_HSD](http://www.toyota.com/vehicles/minisite/hsd/index.html?s_van=GM_TN_HSD)
110. <http://automobiles.honda.com/civic-hybrid/>
111. <http://www.fordvehicles.com/suvs/escapehybrid/>
112. [http://www.gm.com/explore/fuel\\_economy/hybrids.jsp](http://www.gm.com/explore/fuel_economy/hybrids.jsp)
113. <http://www.theride.org/PRRollOut.asp>
114. <http://www1.eere.energy.gov/hydrogenandfuelcells/production/basics.html>
115. [http://ec.europa.eu/research/energy/pdf/hlg\\_vision\\_report\\_en.pdf](http://ec.europa.eu/research/energy/pdf/hlg_vision_report_en.pdf)
116. <http://www.sciencemag.org/cgi/content/full/308/5730/1901>
117. <http://www.fuelcells.org/thomasstudy.pdf>
118. <http://www1.eere.energy.gov/hydrogenandfuelcells>
119. <http://www.ford.com/innovation/environmentally-friendly/hydrogen/ford-edge-hyseries/edge-fuel-cell-hybrid-346p>
120. <http://www.sciencemag.org/cgi/content/full/308/5730/1901>
121. [http://www.gm.com/explore/education/9-12/fuels\\_energy/hydrogen\\_challenges.html](http://www.gm.com/explore/education/9-12/fuels_energy/hydrogen_challenges.html)
122. <http://www.manuremanagement.cornell.edu/Docs/Fuel%20Cell%20Fact%20Sheet%20-%205-3-05.pdf>
123. [http://www.eere.energy.gov/afdc/vehicles/fuel\\_cell.html](http://www.eere.energy.gov/afdc/vehicles/fuel_cell.html)
124. <http://www.hydrogencarsnow.com/blog/hydrogencars.html>
125. <http://www.alternative-energy-news.info/hydrogen-fuel-cell-bikes/>
126. <http://www.altfuels.org/backgrnd/altftype/hydrogen.html>
127. <http://www.osti.gov/bridge/servlets/purl/230382-aXfCXH/webviewable/230382.PDF>
128. <http://www.sciencedaily.com/releases/2007/10/071003100601.htm>
129. <http://www.washingtonpost.com/wp-dyn/content/article/2006/12/11/AR2006121100120.html>
130. <http://www.msnbc.msn.com/id/4563676/>
131. [http://www.usatoday.com/money/autos/environment/2008-02-25-plug-in-hybrids-pollution\\_N.htm](http://www.usatoday.com/money/autos/environment/2008-02-25-plug-in-hybrids-pollution_N.htm)

## 8 Appendix

See attached excel file

## 9 Project Status Report Approvals

Prepared by \_\_\_\_\_  
Principal Investigator

Approved by \_\_\_\_\_  
Project Manager

