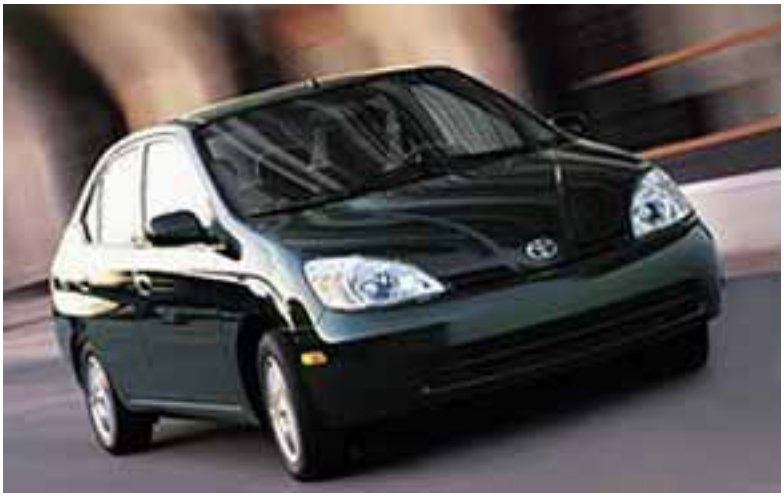
An Evaluation of Hybrid Vehicle Use in a Canadian Fleet Environment

Honda Insight !



Toyota Prius !

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Abstract

Overall, user satisfaction was very high with both the Toyota Prius and the Honda Insight. Fuel economy was approximately three times better than fleet average and there were no limitations due to climatic conditions. Interestingly, while Honda claims 50% better fuel economy than Toyota, in this study fuel economies were equivalent in normal fleet use.

Fuel savings are approximately $1350 per year, assuming 25,000km usage at a cost of 67c/L.

Pollutant emissions are very low, much less than from a normal vehicle, by a factor of 2.5 to 10,000, depending on the pollutant.

Vehicle range is extended, approximately 1000 kms per tank of gasoline.

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1. Executive summary

Today, humans are heavily reliant on the internal combustion engine vehicle for personal, freight and mass transportation. The average North American household owns two to three internal combustion engine vehicles. These vehicles cause dramatic impacts on our environment, since internal combustion engine vehicles are responsible for significant quantities of air pollution. The average family sedan emits about 8 tons/yr of CO_2 and the average SUV emits 12 tons/yr of CO_2. The need for change is evident. In addition, fossil fuels will be used up sooner or later.

Since 1980, the ten hottest years ever were recorded, and scientists have reached a consensus that global warming is already happening. Upgrading vehicle fuel efficiency would cut the emissions that threaten catastrophic climate change, while reducing our dependence on oil and saving drivers money.

Alternatives to gasoline such as propane, natural gas, dimethyl ether or hydrogen are available, although some of these are fossil fuels themselves. Some problems with these alternative fuels are marketing/public acceptance and the development of new fueling infrastructures.

With hybrid vehicle technology, we can significantly reduce air emissions and reduce the consumption of fossil fuels, while using the existing gasoline supply infrastructure in the interim. Currently, the Honda Insight and Toyota Prius are the only mass-produced hybrid vehicles in the world, although a number of manufacturers are promising to bring hybrid vehicles to the mass market in the near future.

This main scope of this study was to evaluate the performance of the Honda Insight and Toyota Prius in a Canadian normal fleet use environment, as part of the Clean Air Hamilton NuVehicle project.

The major advantage of these vehicles, of course, is the large reduction in pollutant emissions, including carbon dioxide emissions.

The Honda Insight is a two seater with good trunk space, while the Toyota Prius is a four seater, approximately Camry sized, also with good storage space. Both cars are fuelled by gasoline. They each cost approximately $30,000 Canadian, with fuel savings offsetting this fairly high initial capital cost for a normal fleet vehicle. Breakeven with normal fleet purchases occurs at the 5 year point, so the hybrid vehicle should deliver significant savings over the remainder of its useful life.

This evaluation reviewed history, specifications, hybrid technology and innovative engineering as well as comparing the fuel efficiencies and pollutant emissions of the Insight and Prius to conventional vehicles and documenting users' comments and recommendations.

Fleet fuel statistics were collected and evaluated, Drive Clean emission tests were performed, fleet user comments were solicited and a web site was set up to collect user comments from a wider group.

Overall, user satisfaction with both of these vehicles was very high. Fuel economy was approximately three times better than fleet average and there were no limitations due to climatic conditions. Interestingly, while Honda claims 50% better fuel economy than Toyota, in this study fuel economies were equivalent in normal fleet use.

Fuel savings are $1350 per year, assuming 25,000km usage at a cost of 67c/L.

Pollutant emissions are very low, up to ten times less than from a normal vehicle. Vehicle range is extended, approximately 1000 kms per tank of gasoline.

The study concluded that both vehicles performed very well under fleet conditions in a Canadian city.

The study was financially supported by the Ontario Ministry of the Environment and Environment Canada, in addition, hybrid vehicles were purchased by MOE, Hamilton Hydro and the HSR (Hamilton Street Railway), the Hamilton mass transit system.

2. Project History

The Nu(Normal use)-Vehicle project was first proposed in July 1998 by staff of the Ontario Ministry of Environment. On February 23rd, 1999, the NuVehicle partnership was formally announced by the Region of Hamilton-Wentworth as part of the Hamilton Air Quality Initiative (now Clean air Hamilton).

The NuVehicle program encourages organizations, businesses and citizens to purchase Hybrid engine vehicles. The original strategy was to have the partners commit 10% of their new vehicle budget to innovative vehicle purchases, then run a competition and select the best vehicles. This was not feasible due to the limited availability of vehicles. Partners in the New City of Hamilton now commit to purchase a minimum of one innovative vehicle that will improve air quality. The program will also advertise Hamilton's interest in improving air quality.

This evaluation of the Nu-Vehicle project was funded by Environment Canada-Ontario Region (EC-OR) and the Ontario Ministry of Environment.

The specific tasks were as follows:

1. Evaluate vehicles purchased in the Nu-Vehicle program.
2. Evaluate driver satisfaction, fuel economy and other relevant aspects of vehicle performance.
3. Test hybrid vehicles for emissions through the Ontario Drive Clean Program.

3. Review of hybrid engine and other alternative vehicles.

What is a hybrid?

A simple explanation of HEVs (Hybrid Engine Vehicles) is that an internal combustion engine and an electric motor work together to drive the vehicle. Energy is also recovered and stored during braking (regenerative braking). Only half the amount of gasoline is used for double the mileage compared to conventional vehicles. Since less fuel is consumed and a smaller internal combustion engine is used, less emissions are produced. If hybrid vehicles capture a significant share of the automobile market, the air environment should improve significantly.

Types of hybrid systems:

There are three types of hybrid systems; series, parallel, and split.

In a series type, a small internal combustion engine designed for constant speed drives a generator. The generator outputs electricity and is used to directly drive the motor and/or recharge the batteries. Since only the electric motor drives the wheels, the motor has to be large enough to meet all the peak demand needs for acceleration. The battery pack then needs to be quite large to supply the large motor.
The series type outputs less power than the parallel and split type, so parallel and split hybrids can climb hills better than the series type. As a result, major car companies like Honda and Toyota have chosen parallel and split type hybrid systems.
In a parallel type, both an internal combustion engine and electric motor drive the wheels. The engine is designed for constant speed and recharges the battery when needed. A small electric motor is used to relieve load from the engine during acceleration. Since the motor is small, only a small battery pack is required.

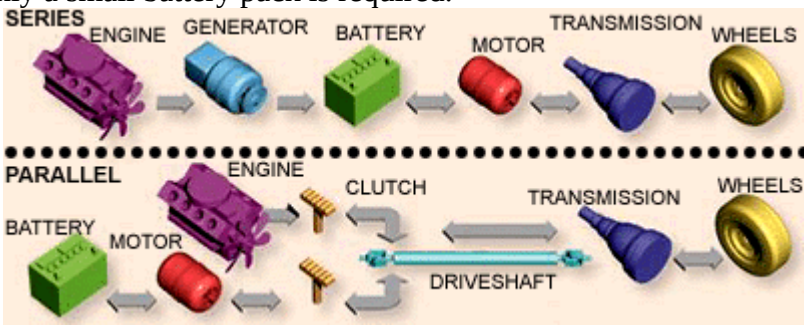


Figure 1.1: A model of series and parallel types.
Parallel and split are similar except the split type is commanded by a computer to use the engine and electric motor alternately.
A split hybrid system is based on the parallel hybrid system, but actuates both a series and parallel hybrid system. During accelerating or cruising at higher speeds, the split type acts like a parallel system. When cruising at low speed or accelerating from a stop, the split system employs a series system. Essentially, the gasoline engine and electric motor work together to maximize fuel efficiency as well as minimize emissions due to less use of the gasoline engine. The main challenge with this system is to design the software and mechanical systems to efficiently integrate the two power sources.

Why hybrid?

At this point in the development of the motor vehicle, Hybrid Engine Vehicles (HEV) are the best of both worlds. They are very good for the environment and consume less fossil fuel. It is important that the public become aware of the very low real efficiency of the internal combustion engine. On average, only about 13% of the actual energy extracted from fossil fuel is used to propel the vehicle, while the rest turns into heat energy, and, in addition, HC, NO_X, and CO_X are emitted. CO_2 is the major source of global warming. With the use of the current hybrid vehicles, we can reduce the global-warming impact of vehicles by 30% to 50%. Clearly, it would be best to optimize the use of hybrid technology until other alternative fuel technologies are available to the public with greater potential to save the environment and reduce the use of fossil fuels.

Working details of hybrids.

The series type hybrid vehicle's drive map is straightforward. The gasoline engine recharges the battery and the electric motor drives the wheels full time. The parallel hybrid vehicles are different. At a stop, the gasoline engine shuts off to avoid any use of fuel and unnecessary emissions. During initial acceleration, the internal combustion engine is assisted by the electric motor. During cruising, only the gasoline engine propels the vehicle. When decelerating, the fuel is cut and the electric motor acts as a generator to recharge the battery. This is called regenerative braking. When the vehicle is at a stop, the engine shuts off automatically.

Hybrid vehicle vs. Electric Vehicle

The concept of an EV (electric vehicle) is simple. A battery powers the electric motor and the electric motor drives the wheels. The main factors that separate HEVs and EVs are range, convenience, impact on the environment, and cost.

Unlike HEVs, an EV requires 3-8 hours to recharge the battery. The charge time is very inconvenient for those travelling longer distances or for commuters beyond a certain range. A critical drawback is the distance traveled per charge. The EV can only travel roughly 130 kilometers on each charge whereas the HEV can travel up to 1000 kilometers with one full tank. So, the EV requires advanced battery technology to extend its range and shorten charging time.

Currently, the Honda Insight and the Toyota Prius cost around $30,000 in Canadian dollars with most options included, while the cost of GM's EV1 is around $75,000 in Canadian dollars. As a result, the EV is too expensive for an average family as well as having insufficient range.

Clearly the best alternative for the environment is an EV because it emits zero local emissions and centralized electricity production is always less polluting than individual portable electrical generators. However, the HEV emits up to 90% less pollution than the average family sedan. Therefore, the HEV is the best practical alternative vehicle at present. In the future, an EV with electricity generated by a fuel cell will probably be the best alternative vehicle.

Fuel Cell vehicles vs. Hybrid and Electric vehicles

One can argue that the fuel cell is like a battery, which does not require charging as long as the hydrogen or source of hydrogen is provided. The fuel cell is environmental friendly; it produces electricity, water and heat energy. Therefore, the fuel cell has a wide range of uses, e.g., home power generation, electronics devices, automobiles and portable electronics such as portable music players or digital cameras,. Within the fuel cell device, a chemical reaction takes place as hydrogen or other fuel is combined with oxygen to produce electricity, with water as a byproduct.

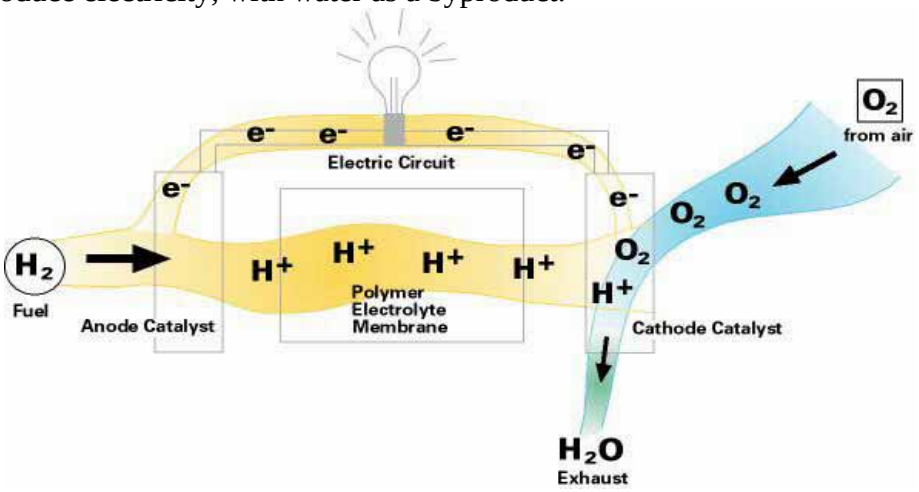


Figure 1.2: Basic internal operation of a fuel cell.

Hydrogen is fed into the anode catalyst where the electrons from the hydrogen atoms are stripped off to generate electric current. The hydrogen ions then react with oxygen to form water. There are no emissions except water and heat. This gives the fuel cell the greatest advantage over a hybrid system. Also the fuel cell has an ultimate advantage over a battery-powered EV since the fuel cell can extend the vehicle range. The disadvantages of the fuel cell are capital costs, storage and cost/availability of hydrogen. Fuel cells and other related components are still very expensive.

Hydrogen is a very explosive element and needs to be stored at high pressure (~2000PSI). In case of a car accident, the hydrogen storage must be highly engineered to keep the hydrogen safe, although storage systems are now approaching appropriate safety standards. Hydrogen is expensive compared to fossil fuels, it is difficult to extract and hard to manage. Cheaper ways to produce hydrogen are currently being researched and developed.

Current fuel cell technology is not ideal but it possesses the potential to become the future of private energy sources. Many major auto companies are currently researching combinations of hybrid and fuel cell technology.

Types of Fuel Cells

There are many types of fuel cells such as Phosphoric Acid, Proton Exchange Membrane, Molten Carbonate, Solid Oxide, Alkaline, Direct Methanol, and Regenerative Fuel Cells. Fuel cells do not necessarily require hydrogen as a feedstock. With a device called a reformer, fuels such as gasoline, methane, and ethanol can be used. The reformer consumes fuels such as gasoline, methane, and ethanol to produce hydrogen and emission

gases. So far, the most popular type of fuel cell is in the proton exchange membrane fuel cell because it operates at low temperature, provides high power density, and hydrogen conversion is rather fast. Using a reformer to power a fuel cell is not ideal since it produces similar emissions to HEVs.

4. Project Vehicles, Honda Insight and Toyota Prius

Honda Insight

The Honda Insight is the second mass produced gasoline-electric hybrid vehicle to be sold in the world. The Insight employs a parallel hybrid system. The Insight's primary power comes from a 3 cylinder, 1.0 liter, 63 horsepower 12 valve SOHC VTEC-E™ engine. A maximum of 73 horsepower at 5700 rpm is available and 91 foot-pounds of torque at 2000 rpm, with approximately one-third of this torque being supplied by the IMA™ (Integrated Motor Assist) electric motor.

To minimize the emissions and maximize fuel efficiency, the Honda engineers reduced the weight of the engine, reduced engine friction, employed a manual transmission, and designed the engine to intake a greater air-gasoline ratio. The engine is made of materials such as aluminum, magnesium and special plastics to reduce weight. To reduce friction, the pistons have been microscopically dimpled, OW20 engine oil is used to enhance lubrication, the rocker arms are placed with rollers to reduce friction on the cam's contact surfaces, and the combustion pressure is maximized by eliminating the lateral friction between the rod and the crankshaft. The microscopic dimples on the pistons allow a larger amount of OW20 engine oil to distribute evenly. Since automatic transmissions have about 20% driveline power loss while a manual has only a 10% drive line power loss, manual transmissions are used. This increase in power transmission efficiency gives more wheel-torque for acceleration. To eliminate the lateral friction between the rod and the crankshaft, Honda placed the bore center 14mm from the center of the crankshaft so that the rod will only move up and down in the cylinder. The average 1-liter engine intake air-gasoline ratio is 14.7:1 but the Insight's air-gasoline ratio is 22:1. This means that the Insight's 1-liter engine requires less fuel to operate at the same performance as a normal 1-liter engine. Also, the VTEC-E™ optimizes valve timing to maximize the performance of the engine. As a result, the Honda Insight's engine uses less fuel for optimal performance.

Honda's multifunctional electric motor is a 10kW ultra-thin permanent magnet DC brushless motor. The MCM (Motor Control Module) controls the electric motor to assist the gasoline engine during acceleration, or climbing a hill, and also to generate electricity. The electric motor can provide up to 15 horsepower and is powered by a 144-volt nickel-metal hydride battery pack controlled by a BCM (Battery Condition Module). The motor is used as generator to recharge the batteries when braking or decelerating. This is called regenerative braking. The MDM (Motor Drive Module) directs the electricity generated by the electric motor to the nickel-metal hydride battery and the 12V battery used for the electrical system. When the engine increases its speed, the crankshaft vibrates because of the imbalance of the 3-cylinder engine. The electric motor then switches to regeneration mode to absorb the vibration. When the crankshaft loses its speed, then the electric motor activates to increase the speed. The electric motor is indeed multi-functional. It reduces cost since there are fewer components used.

The Honda Insight offers sophisticated body and safety engineering. Generally, most of the weight of the automobile is concentrated in the body. In order to minimize the weight of the Insight's body, Honda engineers used aluminum for construction. Aluminum is very light but can be relatively weak. So, Honda engineered the body to make the structure behave well above U.S., European, and Japanese safety standards. Thus,

compared to a normal steel body structure, the Insight has a 13 percent increased bending strength, 38 percent increased torsional rigidity and 47 percent less total weight. The Insight's aluminum space frame with composite body panels weighs 815 kg. Another innovative body structure applied to the Insight is the stressed sheet-metal panel technology used to absorb and distribute structural and suspension loads. Stressed sheet-metal panels are used on the roof, floor, front and rear wheel wells, rear quarter-panels, bulkhead, and even the doors and hood. The Insight possesses many safety features such as front and rear crush zones that help absorb full-frontal and offset-frontal impacts, and a passenger compartment that is reinforced against side impacts. The Insight's body uses very innovative engineering.

The Insight is a two-seater car with a reasonably large cargo area. The Insight's aerodynamic body structure and relatively low weight provides the lowest coefficient of drag ratio (0.25) of any mass-produced automobile in the world. The Insight's body style includes rear fender skirts, which help the air to smoothly glide past the rear wheel wells. The two-seater resembles a blend of the rear of a futuristic CRX and a super-sleek Civic front. With the low drag ratio, the Insight travels 0-60 mph in 10.5 seconds. Another means to achieve low air friction is the height of the car. It sits low to the ground, standing a mere 53 inches high. And thereby lies a potential fault, drivers need to be mindful of the vehicle's low clearance.

A good feature is the size of the numerals on the digital speedometer. High contrast makes the display very easy to read and understand. The display also reveals when and how much the batteries are being charged. The state of charge of the Insight's nickel-metal-hydride batteries is an important indicator, since battery durability is a critical issue in hybrid-electric vehicles. The car also uses low friction tires, all in the interest of better fuel economy.

The Insight handles well and gets approximately three times better fuel economy than a regular vehicle for each tank of gasoline. The Insight has the usual conveniences such as power windows, steering, mirrors, and door locks. However, air conditioning is optional. The Insight gets about 3.73 liters per 100 kilometers and runs so cleanly that it meets California's stringent Ultra-Low Emission Vehicle standard. The Insight as a whole is covered by Honda's normal 3-year bumper-to-bumper, 5-year major component warranty.

As a show of Honda's confidence in their new technology, components that form the hybrid powertrain are covered for 8 years, i.e., the IMA™ motor, battery pack, computer controllers and even the wiring between these components.

Toyota Prius

The Prius is the first mass produced hybrid vehicle in the world. Prius—from the Latin word meaning, "to go before" is the name of Toyota's hybrid. Toyota intends the name to mean "genius".

After introducing the Prius at a 1995 auto show, Toyota set an aggressive development schedule to bring the Prius to market in just two years time, in a successful effort to be the first car company in the world to offer a production hybrid-electric car for sale. The Prius employs a split hybrid system but with intelligence, meaning the control system thinks and actuates to minimize fuel consumption and emissions. The intelligence comes from the innovative THS^{TM} (Toyota hybrid system). The THS delivers power to the

wheels depending on the load and speed, to keep the vehicle in most efficient mode. Thus, the THS continuously monitors the ratio of power provided by the different systems in the vehicle. The THS is like the motherboard in a computer and there are a number of innovative technologies employed.

The Prius employs a sophisticated and advanced gasoline engine and an electric motor. Since the highest level of fuel efficiency is reached when the engine is running at constant velocity, i.e., cruising, the Toyota team of engineers designed the engine for cruise operation. Toyota made the crankshaft thinner, decreased tensile strength in the piston rings, and reduced valve spring load. As a result, the engine's rpm is limited to 4000 rpm producing 58-horsepower from a clean 1.5-litre DOHC, (Double Overhead cam with Electronic Throttle Control) 16 valve engine with VVT-i^{TM}, (Variable Valve Timing with intelligence) and an all aluminum block and head. The air to gasoline ratio is 13:1 to consume less fuel for equal performance. Incorporating VVT-i improves mid range torque, maximizes fuel economy, and lessens emissions. Toyota estimated that only 1% of drivers use full power. So, by limiting engine revolutions to 4000 rpm, internal parts can be built lighter and smaller, which translates into increased efficiency. The zero-exhaust electric motor is permanent magnet based and output is 33kW or 44hp at 1040 rpm to 5600 rpm, providing 350 N-m or 258 lb.-ft of torque at 0-400 rpm. The motor power is supplied from a 273.6V stack of nickel-metal hydride (NiMH) batteries. The battery unit is completely sealed to prevent electrical or magnetic field interference or leakage of harmful chemical agents.

The Toyota Prius is simply an engineering marvel. The unique aspect of the THS is the computerized power-split transmission called a planetary gear (see Appendix C) which balances the input and output of the gasoline engine, generator and electric motor to accommodate acceleration and deceleration. Thus, the Prius is infinitely variable in its ratio of gasoline to electric power, depending on a variety of inputs and making seamless transitions. When the Prius is started, it's very quiet. It doesn't make any noise or emit any pollutants from the tailpipe when you start moving from a dead stop, because at that moment the vehicle gets its power exclusively from the batteries and the electric motor as it produces 100 percent of its maximum torque. When the vehicle reaches 25 to 40 km/hr, the generator starts the engine and the electric motor is used to supplement acceleration. The Prius can accelerate up to a top speed of 160 km/hr in short bursts using the engine and batteries together. When power requirements change, the THS diverts output from the generator to recharge the batteries whenever they are low. A regenerative braking system recovers energy from the wheels during downhill driving and braking and uses it to generate electricity. Approximately 30% of braking energy transfers to the battery and the rest becomes heat energy. Therefore, batteries never need to be recharged from an external source.

Prius can travel approximately 950 kilometers on one full tank of fuel.

The brain of the driving operation is referred to as the ACS and it is specially programmed to minimize fuel consumption during city driving. The ACS (Advanced Control System) decides when to activate the gasoline engine and/or electric motor depending on the driver's style to maximize fuel efficiency and minimize emissions. Both the gas engine and electric motor are used equally and the driver may notice the engine starting and stopping depending on the situation.

During initial acceleration, or when engine demand is low, the electric motor is the primary source of power. When cruising at greater than 50km/h or normal driving condition, the gasoline engine engages and its ratio of power input to that of the motor is controlled for maximum efficiency. At full acceleration or climbing hills, the cruising or normal driving mode is boosted by power flowing from the battery for smooth yet powerful response. During decelerating or braking, the gasoline engine turns off and the electric motor functions as a generator to charge the battery. When the vehicle is stopped, the gasoline engine shuts off automatically and the electric motor stands ready to power up the Prius. This conserves fuel and eliminates exhaust emissions caused by idling. Also, the engine stays on long enough to ensure the batteries are charged up and the coolant reaches operating temperature, then the engine shuts off. This improves both fuel economy and emissions, as well as reducing wear and tear, presumably meaning fewer oil changes and longer engine life. The Prius performs better in stop-and-go traffic, when it is either idling or moving slowly. In Japan, the narrow streets and congested highways require lots of stop-and-go maneuvers. Wide-open highways are rare, as compared to the Canadian experience where highways are heavily used.

The Prius is a four-door family sedan, with an interior volume comparable to that of the mid-size Camry sedan. The design is taller than we normally expect. Many vehicles of the next decade will reflect this 'function over form' design concept, e.g., the Ford Focus, Chrysler PT Cruiser and many designs being sold in Europe. Prius combines the short overhangs and large, relatively upright cabin necessary for a newly designed city vehicle. Prius' high front and rear seating positions offer excellent visibility. The instruments are centered high on the dash, and the speedometer is positioned at the top and center of the dashboard, closer to the natural line of sight. Toyota researchers found that this raised the safe driving speed, especially for older, slower drivers, by as much as 18 percent. The audio system is located below the instrument cluster, as is a multi-function monitor which shows the condition and energy flow of the hybrid drive system and which can also be used for a navigation system display. Driver and passenger-side airbag supplemental restraint systems (SRS) are standard. The Prius was designed to meet or exceed every known and foreseeable worldwide crash-safety standard.

Sustainable resource management has also been considered in the design of this vehicle. The Prius is designed and built to be easily recycled. TSOP (Toyota Super Olefin Polymer), a recyclable resin developed by Toyota, is used extensively for normally difficult to manage plastics both inside and outside the vehicle. Also, Toyota is already organizing a program to handle its end-of-life recovery and recycling of batteries. All this translates into less resources being used and less waste for the future.

Prius' exterior design is sophisticated looking and aerodynamically efficient. The air drag ratio is 0.29. It is a sedan type vehicle with large doors for easy exit/entry and a low lift over trunk height for easier loading and unloading. The undercarriage is flat for better aerodynamics.

Insight vs. Prius

Honda Insight and Toyota Prius are among the most innovative and technologically advanced cars ever for sale worldwide. There are numerous differences between the two vehicles, but here are some key points: Insight is primarily powered by its gasoline engine with battery assist, while the Prius uses whichever motive power is most efficient

at the time, at low speeds, this is primarily the electric motor; Prius uses proprietary technology called the Toyota Hybrid System (THS) which switches between gasoline and electricity, as driving needs change. The Honda Integrated Motor Assist uses a basic parallel hybrid system with an electric motor. Prius is a five-passenger, four-door sedan with more interior volume than a Corolla. The Honda Insight is a two-passenger, two-door coupe. Prius uses conventional steel body panels. The Insight has an aluminum monocoque body. Honda's Insight meets California's Ultra Low Emission Vehicle (ULEV) standards. Prius meets Super ULEV standards, a level approximately 75% cleaner than ULEV and approximately 90% cleaner than the average conventional vehicle on the road. The Insight is currently offered with a standard transmission or automatic continuous variable transmission CVT system. Prius is available with an automatic CVT system. Both cars have many differences and performance/emissions, features and technology will be explored.

Table 1.1: Manufacturer's Specifications for Honda Insight and Toyota Prius.

	Prius	***Difference***	**Insight**	***Advantage***
Fuel Economy (L/100km,city)	4.5	**0.6**	3.9	**Insight**
Fuel Economy (L/100km,highway)	5.2	**1.7**	3.5	**Insight**
Horsepower	70	**3**	67	**Prius**
Acceleration (to 100km/hr, s)	13.7	**3.1**	10.6	**Insight**
Range (km)	930	**-170**	1100	**Insight**
Curb weight (kg.)	1254	**402**	852	**Insight**
Seating capacity	5	**3**	2	**Prius**
Exterior Dimensions (cm.)				
Overall height:	146	**11**	135	**Prius**
Overall width:	169	**0**	169	**-**
Overall length:	431	**37**	394	**Prius**
Wheelbase:	255	**15**	240	**Prius**
Coefficient of drag (Cd):	0.29	**0.04**	0.25	**Insight**
Interior Dimensions (front, cm.)				
Head room:	99	**0**	99	**-**
Shoulder room:	134	**6**	128	**Prius**
Hip room:	129	**5**	124	**Prius**
Leg room:	105	**-4**	109	**Insight**
Passenger volume (cu. metre)	2.51	**1.17**	1.34	**Prius**
Cargo volume (cu. metre)	0.334	**-0.128**	0.462	**Insight**

For detailed specifications, please see Appendix B.

Performance/Emissions – Manufacturer's claims

In order to meet North American driving standards, Toyota upgraded Prius' horsepower. Car & Driver magazine reported that Prius' 0 to 100km/h is 13.7 seconds, compared to the Insight's 10.6 seconds. In terms of speed, the Insight has the ultimate advantage in

overall weight, hybrid system, and aerodynamic drag. The Insight is 400 kilograms lighter, has more horsepower per cylinder, 0.04 lower aerodynamic drag, higher limit of rpm and, since it has a parallel hybrid system, the engine is on full time during motion. Prius has another disadvantage since it ignites its engine during acceleration.

Fuel efficiency/Emissions

The claimed fuel efficiency of both cars far exceeds that of average compact cars. According to the manufacturers, Insight gets 3.4 L/100km (61/70 mpg) and Prius gets 4.9 L/100km (52/45 mpg). However, emissions from Prius meet California's SULEV (Super Ultra Low Emission Vehicle) level and the Insight's emissions meet California's ULEV (Ultra Low Emission Vehicle) level. The Prius' emissions are lower even though it consumes more fuel because the THS does not allow the Prius to have its gasoline engine on fulltime. So although the Honda Insight has a lean burn gasoline engine, the Toyota Prius has an advanced brain.

Safety

Safety tests for the Insight and Prius were very successful. Both are among the safest compact cars available. Honda's advanced body design makes up for weakness of the aluminum alloy. Toyota Prius and Honda Insight have very similar safety standard features, such as anti-lock brakes, door beams distributing the load of side impacts, dual airbags, and traction control.

Drawbacks

According to the Internet Yahoo Honda Insight Group, the Insight's three main drawbacks are that it is only a 2 seater, low weight capacity and limited rear view. The Prius Internet Group reported that the three main drawbacks for the Prius are acceleration, appearance, and unstable handling at +120km/h.

Interior

The Insight's interior is designed to be a sporty and appealing like the exterior and performance. This includes the steering wheel design and high back, supportive bucket seats with two tone gray and black mesh fabric. When you sit in the Insight, you find that there is a lot of headroom and everything is conveniently at hand. As for Prius, Toyota's sophisticated space design permitted Prius to have an optimum interior space but minimum exterior volume. As a result, Prius provides plenty of room for a driver and 4 passengers.

Beyond the differences in format, the Insight and Prius have a lot in common in terms of features. For example, both cars have automatic climate control systems, keyless remote entry, anti-theft immobilizer systems, standard power windows, locks and mirrors, and digital instruments (though in the Prius they are center mounted rather than in front of the steering wheel).

Figure 2.1: Interior design of Insight

Figure 2.2 & 2.3: front side interior design of Prius and zoomed picture of electronics display of Prius.

Exterior

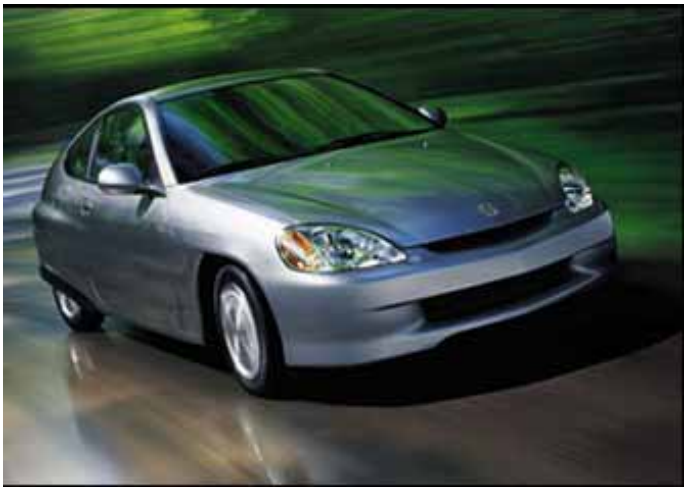


Figure 2.4: Honda Insight exterior.

Figure 2.5: Toyota Prius exterior

Technology

Aerodynamics

Both Honda and Toyota recognized the importance of aerodynamics when building a fuel-efficient car. After all, when travelling at high speed, increasing amounts of energy are lost due to air drag.

Aerodynamic features common to both cars are smooth plastic underbody panels that reduce air turbulence under the car. Other important similarities are: teardrop shaped bodies, narrow body width while the rear hatch gently slopes down and the rear underbody slopes up by 15º, air dams in front of all four wheels, enclosed rear wheel wells, optimally shaped front air intakes, and even aerodynamic mirror covers.

Weight Reduction

Both Honda and Toyota have reduced the weight of the engine to reduce friction and fuel consumption. However, Honda reduced more weight by constructing an aluminum monocoque body. This body reduced 40% of the overall weight and is the main reason the Insight is 400 kilograms. lighter than the Prius.

Air conditioning

The Prius has partially polarized glass which reduces the transmission of heat and UV and uses an air conditioning compressor specially designed to operate with the small, intermittent use engine.

Powertrain

The powertrain is the most complex technology in the Insight and Prius, with both similarities and differences. The major differences between Prius and Insight are how each power source is used. In the Insight the gasoline engine is always running while the Prius only uses its gasoline engine when needed. Prius is mainly designed for city driving

so the car uses its electric motor during initial start up instead of using both the motor and combustion engine. The electronic CVT (controlled variable transmission) provides seamless, smooth acceleration and deceleration.
There is about a one second penalty in accelerating a Prius because the engine starts while you are accelerating. Though it is seamless, it takes a second for the transformation from electric only to hybrid propulsion.

Automatic regeneration system

When a hybrid car is coasting or the brakes are applied, kinetic energy – the energy of motion—is captured from the wheels and channeled to the battery. Automatic regeneration extends the life of the battery 60 percent.
Both cars turn the gas engine off while idling and use both engine and motor when full thrust is needed.
The Insight and the Prius are only significantly different in how they use the electrical storage. In some situations, Prius will use its electric motor only. The Prius thus has a larger battery and electric motor than the Insight (also because the Prius is a 5-passenger car and the body is made of steel compared to the aluminum body of the Insight).

Powertrain system

The Hybrid system configuration.
Insight

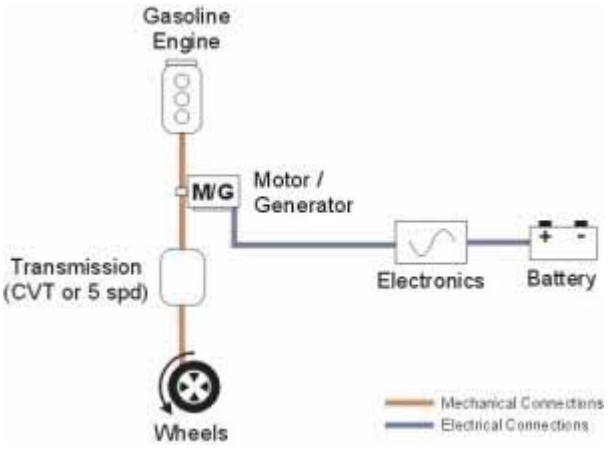


Figure 3.1: Honda Insight's Hybrid powertrain.

When the Insight begins to move, it instantly starts its gasoline engine. This instant start is accomplished by using the electric motor. Insight uses one motor for driving the wheel, starting the gasoline engine, and recharging the battery. When the ACS detects a heavy load, it draws power from the battery and directs it to the electric motor to relieve the load from the engine. Heavy loads occur when accelerating and driving uphill. During braking and decelerating, the motor recovers energy by regenerative braking to recharge the battery.

Prius

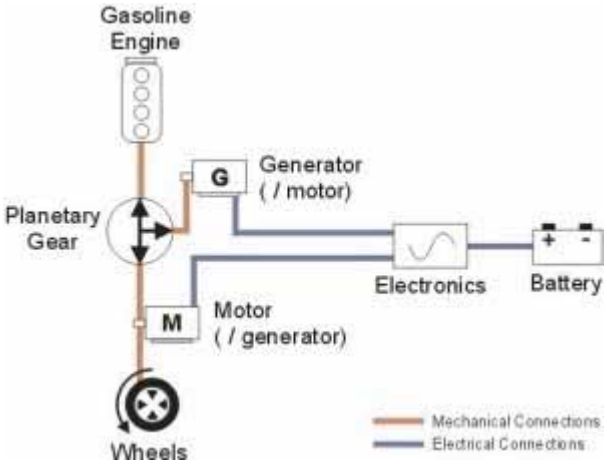


Figure 3.2: Prius' Hybrid powertrain.
Prius' planetary gear is detailed in Appendix D

Prius uses two motors, a generator and a motor. The Generator (G in the figure above) is used to recharge the battery from the gasoline engine, and to start/stop the gasoline engine. The Motor (M in the figure above) is used to drive the wheels and recharge the battery from regenerative braking.
When the Prius begins to move, M draws energy from the battery to put the car in motion. Since the gasoline engine is not yet active, all movements of the wheel side of the planetary gear is directed towards G.
When the THS detects a load too great for the electric motor to handle, usually between 25 and 40 km/hr, G starts the gasoline engine. The amount of additional propulsion will vary depending on the amount needed.
Reverse motion is actuated by M, the electric motor. The electrical system simply directs opposite current to reverse the motion of the electric motor.

Prius's split hybrid type allows a more flexible use of motive power, leading to greater efficiencies and lower emissions, however, the planetary gear does cause some energy loss by force of friction.

Low Rolling-Resistance Tires

Both the Insight and Prius use low rolling resistance tires to improve efficiency. In fact, both use the same tire model, Bridgestone Potenza RE-92, though in slightly different sizes since the Prius weighs more.
The low-rolling resistance tire reduces deformation by using relatively low profile tires and fairly high pressure. The Insight takes this slightly further, using165/65R14 format, and recommended tire pressures of 38 PSI front, 35 PSI rear, as compared the Prius's 35/33 PSI pressures.

Gasoline Engine Technologies

Even the gasoline engines in the Insight and Prius are designed for very efficient and clean operation. Emissions are reduced using precise control over spark timing and fuel

injection on a per cylinder basis. Both engines use their respective company's variable valve timing technology, and both incorporate significant friction reduction elements.
However, there is one major way in which the two companies took different approaches to improving the engine's efficiency.
Unlike most cars, including the Insight, the Prius uses the Atkinson cycle, where the exhaust valve doesn't close until after the upward stroke has begun. This effectively results in a higher expansion ratio than compression ratio. The Atkinson cycle improves overall efficiency, though it does so at the cost of power.
The Insight takes a different approach to improving the gasoline engine's efficiency, by operating the engine at very lean air-fuel ratios when less power is needed. Unlike most cars, including the Prius, which operate at a "stoichiometric" air-fuel ratio of 14.7:1, the Insight is designed to operate at air-fuel ratios as lean as 22:1.

Advanced Catalytic Converters

Both the Insight and Prius include special catalytic converters to reduce smog-forming emissions.
In addition to improving efficiency, the Insight's lean burn technology allows it to reduce HC and CO emissions. However, lean burn conditions normally result in high NOx emissions. The Insight deals with this by using a special lean-NOx catalyst. Overall, this system reduces HC, CO and NOx emissions, the three things measured by the California XXLEV standards, to very low levels.
Rather than using lean burn technology to reduce HC emissions, the Prius uses a special HC catalytic converter. This catalyst captures unburned HCs after a cold start of the engine, when HC emissions are normally at their highest.
The Insight takes a different approach to lowering cold-start emissions, by getting the catalyst up to temperature quickly. Insight's unique integrated head/exhaust manifold helps get the engine up to operating temperature quickly, and a 3-way catalyst is attached directly to the head/exhaust manifold so that it will heat up more quickly.
When first started, both cars keep the gasoline engine running to get the catalytic converters up to temperature as quickly as possible.

Pollutant Emissions

Evaporated fuel

To reduce emissions of evaporated fuel, the Prius uses a resin-bladder fuel tank that isolates the fuel from the air in the tank. Insight uses a plastic fuel tank for weight savings, but doesn't have a bladder. Insight does, however, have on-board refueling vapor recovery system.

Greenhouse gas emissions

Total green house gas emissions (CO2) are;
Insight 93.5 g/km
Prius 133.7 g/km
Solectria Super Force (all electric) 81.9g/km

Note that the all-electric Solectria Super Force still has the lowest greenhouse gas emissions. This was the only 2 or more passenger vehicle to do better than the Insight.

5. Fuel Efficiency - Normal pooled vehicle use statistics.

The normal pooled vehicles used by the partners in the Nu-Vehicle program are commercially available internal combustion vehicles such as Luminas, Impalas, Aerostars, pickup trucks, etc., with the majority being sedans with at least a 6 cylinder engine.

Fuel efficiency of normal pooled vehicles.

Ministry of the Environment, West Central Region (Hamilton), Technical Support Section.

MOE Normal fleet average -- 13.1 L/ 100 km.

Hamilton Hydro

Car Make and Model	Fuel Efficiency (L/100km)
Ford Windstar LX	14.99
Chevolet Lumina	12.32
Plymouth Grand Voyager	13.19
Average	**13.50**

Hamilton Hydro Normal fleet average -- 13.5 L/ 100km

1. Fuel efficiency - Hybrid vehicle use statistics

Ontario Ministry of the Environment

Honda Insight -- 4.9 L/ 100km

Fuel economy was measured from records of kilometres travelled and fuel receipts.

The Honda Insight was driven mainly on the highway, which explains the high fuel efficiency.

The fuel economy was calculated from records of kilometres travelled and fuel receipts. The Prius was driven city and highway equally.

Toyota Prius – 5.1 L/100km

Hamilton Hydro

Toyota Prius -- 4.2 L/ 100km

Fuel economy was measured from records of kilometres travelled and fuel receipts.

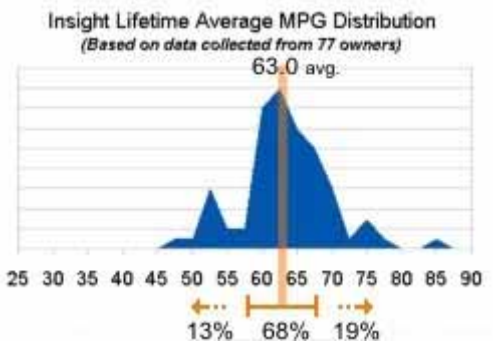
HSR (Hamilton Transit)

HSR purchased two Honda Insights.

Honda Insight -- 4.7 L/ 100km
Honda Insight -- 4.8 L/ 100km

In this case, fuel economy was estimated by the in-car system (shown on dash display) which may not be as accurate as fuel and kilometre records.

According to the www.Insightcentral.net



Overall Average: 3.75 L/100km

Comparison of fuel efficiency results to manufacturers' projections

Both vehicles performed outstandingly in terms of fuel efficiency, approximately three times the normal fleet average.

It is noteworthy that, in this test, using the most accurate system of measurement, the Insight and Prius had similar fuel efficiency over nearly one year of operation, although Honda claims to have 50% better fuel efficiency than Toyota for their respective hybrid vehicles. Claimed efficiencies were Insight - 3.4 to Prius' 4.9 L/ 100km, actual were Insight – 4.9 L/ 100km, Prius – 5.1 L/ 100km.

Using the in-car/dashboard display measurement, the HSR Insights averaged 4.75 L/ 100 km.

Additional statistics were obtained from Environment Canada dynamometer testing, for both fuel efficiency and emissions.

Environment Canada, Technical Services Branch, Emissions Research and Measurement Division

TOYOTA PRIUS

URBAN DYNAMOMETER DRIVING CYCLE (UDDS)					
Date	**CO (g/m)**	**CO2 (g/m)**	**NOX (g/m)**	**THC (g/m)**	**Fuel Efficiency (L/100 km)**
Jan-01	0.120	158.030	0.025	0.010	4.190
HIGHWAY TEST CYCLE (HWFCT)					
Jan-01	0.045	143.420	0.010	0.001	3.805
AGRESSIVE CITY DRIVING (US06)					
Jan-01	0.03	189.21	0.015	0.001	5.015
AIR CONDITIONING TEST CYCLE (SC03)					
Jan-01	0.105	176.54	0.015	0.0005	4.685

Honda Insight

Test Date	Odometer	THC	NMOG	CO	NOx	HCHO	CO_2	Test	F.C	Temp
Dec 2000	Km	g/mi	g/mi	g/mi	g/mi	g/mi	g/mi	TYPE	L/100Km	C°
13	10,069	0.04	0.03	0.23	0.04	N/A	NA**	UDDS	NA**	24
13	10,102	0.00	N/A	0.01	0.35	N/A	NA**	HWFCT	NA**	26
15	10,133	0.03	0.02	0.44	0.04	0.00030	150	UDDS	4.0	26
15	10,166	0.00	N/A	0.01	0.28	N/A	109	HWFCT	2.9	28
20	10,196	0.03	0.02	0.52	0.05	N/A	154	UDDS	4.1	31
20	10,230	0.01	N/A	0.06	0.20	N/A	107	HWFCT	2.8	34
Average UDDS (Std.Temp.)		0.03	0.02	0.48	0.05	0.00030	152		4.04	
Average HWFCT		0.01	N/A	0.04	0.24	N/A	108		2.87	
LEV										
FTP STANDARD										
Emission max. @ 80000KM		N/A	**0.075**	**3.40**	**0.20**	**0.015**	N/A			
		0.008	0.006	0.219	0.000	0.0000	N/A			
			0.029	0.70	0.05	0.0003	N/A			
		N/A	**0.090**	**4.20**	**0.30**	**0.018**				
			0.012	0.458	0.000	0.0000				
			0.035	0.94	0.05	0.0003				

Other data show that fuel efficiency can vary significantly with temperature.

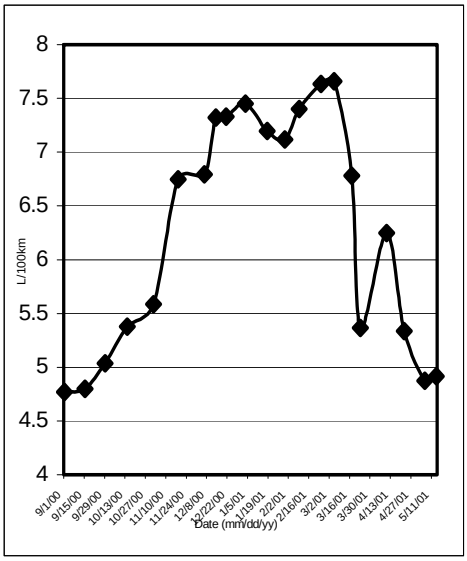


Figure 4: Fuel efficiency during winter season. (Data obtained by Lee A. Hart)

This figure was generated to show the effect of cold temperature on fuel consumption of the Toyota Prius. Low temperature decreases fuel efficiency significantly because Prius tries to keep the catalytic converter at optimal temperatures.

Assuming that the price of regular unleaded fuel is 67 cents/litre and each vehicle travels 25000 km/yr., then gasoline cost/yr for MOE per vehicle will be:
Toyota Prius: $854.25
Honda Insight: $820.75
MOE fleet vehicle: $2194.25

Therefore, the Toyota Prius saves $1340/yr. and the Honda Insight saves $1373.50/yr. in fuel costs.

8. Emission Test Results, Drive Clean Tests

Honda Insight's Drive Clean test results at 2233 rpm

Average HC ppm	7
Average CO %	Not detected
Average NO ppm	Not detected

MOE Fleet Average Drive Clean test results at 1520 rpm.

Average HC ppm	17.2
Average CO %	0.052
Average NO ppm	221.83

*The Winnebago's emission record was excluded due to incomplete test result.

Michael Cho assumed that the average CO % of a Honda Insight is at or less than 0.0049 % and the average NO ppm is at or less than 0.049 (detection limits of measurement devices).
He concluded that the Honda Insight's average HC is 40.7 % of the MOE fleet average. CO and NO are 9% and 0.02% or better respectively of fleet average. As a major health impact contaminant, NOx reductions are very desirable.

Since the Environment Canada data on emissions is measured in grams/mile, M. Cho contacted David Petherick, of Drive Clean to enquire about the unit conversions for Drive Clean test results. He said that it is impossible to convert data accurately from gram emissions per mile to CO% or ppm. In order to convert CO % to CO g/mi., one must recalculate all variations such as mass of fuel entering each cylinder, rpm, load and velocities during testing. All 240 sets of calculations would require new variations for each vehicle.

We were unable to successfully test the Prius using Drive Clean testing equipment, due to the unique drive train configuration which would run "electric only" during standard test conditions. Obviously this would give zero emissions, an unrealistic estimate for normal driving.

Further details of test attempts are given below as well as U.S EPA test results.

Test results of Toyota Prius by U.S EPA (Environment Protection Agency)

Average HC ppm	0.06
Average CO %	0.005
Average NO ppm	N/A

M. Cho has obtained U.S EPA's emission test results from its website. By comparing the U.S EPA's emission test results to MOE's fleet emission test average results, Toyota Prius showed emissions of 0.3% HC, and 9.6 % CO compared to MOE fleet averages.

Toyota Prius test attempts

The first attempt to Drive Clean test the Toyota Prius was unsuccessful due to the Toyota Hybrid System (THS). The test dynamometer requires a minimum of 2250 rpm and a minimum speed of 40 km/h. At the Toronto Ministry of Transportation Drive Clean Testing facility, the Prius' THS limited the rpm to 2249 and a maximum speed of 29km/h. The THS sensed there was no load on the car and so did not ignite the gasoline engine during the test period. There is a short cut method which allows the dynamometer to measure emissions without reading rpm. However, without reading rpm, the machine cannot calculate percentages of CO and NO. Therefore, the test attempt was not successful.

Toyota emission test attempt log.

Log 1.
The Toyota Prius was brought to the Ontario Drive Clean Testing facility in Scarborough. The Ontario Drive Clean facility had a 2 wheel Dynamometer. The Drive Clean technician, Mr. Theo Martens, who was carrying out the emission testing procedure, had the uniqueness of THS explained to him. The test began as he pressed the accelerator but the THS limited rpm to 2249 and the speed to 29km/h. The dynamometer requires a minimum 2250 rpm and 40 km/h in order to monitor all the emissions with accuracy. The procedure was repeated but the outcome was the same. As a result, the emission test was unsuccessful.
Log 2.
Yahoo internet group site members were polled on how to conduct emission tests on Prius and a brief summary was written of previous attempts to test emissions. Others shared expertise and sent a procedure to place Prius into a maintenance mode during the test. The maintenance mode disables the traction control system to achieve higher speeds. However we still needed to know if a 2-wheel dynamometer was adequate.
Michael Cho also contacted Environment Canada's emissions test laboratory technician, Michel Souligny. He had successfully tested the Prius by applying the maintenance mode and achieved good data. He also used a 2-wheel dynamometer.
Log 3.
Michael Cho attended the Windsor Workshop 2001 in the city of Windsor. At the workshop, he discussed this issue with Toyota Corporate Affairs Manager, Wesley Pratt. Mr. Pratt offered Toyota's assistance and on June 14th, 2001, two Toyota experts came to the Drive Clean facility to help with the test. They pointed out that Environment Canada had "fried" the THS the first time they attempted to test the emissions. The replacement cost was $5000. M. Cho decided to terminate the testing at that point, and use Environment Canada's dynamometer test results.
On the simulated chassis dynamometer urban driving cycle, the Prius would get a fuel consumption of 4.19L/100km or approximately 2.5 times less fuel than an average mid-size vehicle, and over the highway driving cycle - 3.8L/100km or approximately 1.64 times less fuel.
Further, in the urban mode the Prius showed that emissions of carbon monoxide, oxides of nitrogen, total hydrocarbons were approximately 10 times less than normal vehicles, while carbon monoxide emissions were reduced by half. In highway mode, when

compared to an average mid-size car, the Prius showed that the emissions of carbon monoxide were approximately 4 times less, oxides of nitrogen were 6 times less, and total hydrocarbons were approximately 30 times less, while carbon dioxide emissions were reduced 1.64 times.

Synopsis: Prius and Insight are primarily low polluting cars. To pollute the least, the catalytic converter (CC) must be hot. In cold weather, the engine must run longer and more often to heat and then keep the CC hot. When the CC is not up to operating temp, the engine runs in a less polluting, but also less efficient (lower MPG) mode.

9. Driver evaluations of hybrid engine vehicles.

MOE and Hamilton Hydro staff responses can be found in Appendix D, comments from the Insight Central web site can be found in Appendix E, and the Yahoo group's responses can be found in Appendix F.

Throughout the drivers' comments about hybrid vehicles, most responses were positive. According to the Yahoo Group's poll (shown in Appendix F) drivers are very satisfied with the hybrid vehicles.

For the Toyota Prius, from 300 replies, 65% purchased Prius for its innovative technology and to reduce pollution.

For the Honda Insight, from 98 replies, 50% of the owners purchased Insight for its innovative technology and fuel efficiency.

Both vehicles' hybrid technology was heavily favored, although it seems that when buyers primarily desired a fuel efficient car, they chose Insight. As for Prius owners, the innovative technology and low emissions influenced their decision to buy Prius.

71 Yahoo Group members submitted their lifetime fuel efficiency. The average fuel efficiency was 5.3 L/100km.

Too few members have submitted for Honda Insight to calculate the average fuel efficiency.

76% of members who have submitted responses to the poll created by kamus (login name) found that only 1% were disappointed with the Prius.

10. Conclusions and Recommendations

Hybrid engine vehicles are the most practical available transportation solution to help clean the air we breathe. The combination of low emissions and excellent fuel economy make these vehicles a cost-effective step forward in solving the smog problem.

This study showed that the vehicles are about three times more fuel efficient, cost competitive, reliable, much less polluting (by a factor of 2.5 to 10,000, depending on the pollutant), and have an extended range compared to normal gasoline vehicles.

Despite manufacturer's claims, there did not seem to be significant differences in fuel economy between the two cars in real world, normal fleet use, although the Prius is larger (5 seater) and heavier than the Insight (2 seater). This is probably due to a combination of factors, i.e., use patterns, control system design and the fact that, with its manual transmission, the Insight is more sensitive to driver skill level.

Performance, both on the highway and in the city, is equivalent to normal passenger vehicles, in terms of acceleration, top highway speed and comfort. Publication of these advantages is now necessary to overcome consumer resistance to the perception that "electric vehicles" are short range, heavy and impractical.

The immediate future of advanced vehicle technology rests, to a large measure, on the success of cars like the Toyota Prius and the Honda Insight. Bought in sufficient numbers, they can help drive down the costs of electric drive technology. But it will take sufficient customers who are more than just "sunshine patriots" in the energy revolution to prove to the auto industry at large that there is a sufficient market for this 21st century technology now. The alternative is to wait until fossil fuel shortages limit our freedom of maneuver and we are collectively forced into a more rational course of action.

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Yahoo groups: Honda Insight group and Toyota Prius group.

Appendix A

Windsor Workshop 2001 Report

Michael Cho

Since 1983, Natural Resources Canada and U.S. Department of Energy have hosted and sponsored the Windsor Workshop. This year's workshop was held in the city of Windsor and continued to focus on bringing alternative transportation fuels and vehicle technologies into common use. The two other streams were lightweight material technologies and fleet management. I attended the alternative transportation fuels sessions. Many topics ranged from policy, to case studies, to the latest technological breakthroughs. There were a total of ten Transportation fuel sessions. Each session contained different topics. I have summarized all the materials that were covered.

The Workshop opened with featured speaker Jim Motavalli. Mr. Motavalli is the editor of the award winning E Magazine and the author of Forward Drive: The Race to Build "Clean" Cars for the Future, published in 2000 by Sierra Club Books, and Breaking Gridlock: Sustainable Transportation for the Next Century, due in late 2001. Motavalli summarized the future energy crisis and solutions to the problem. He foresees that the world population will grow to be 7.5 billion by the year 2020, 18.5 billion barrels of oil will be consumed per day by the year 2020, and the number of vehicles will reach 1.1 billion. Which means that by the year 2010, the demand will exceed the oil supply. Therefore, every day is critical. He strongly suggested that we need to do more than just planning.

Motavalli stated that the energy crisis in California is not due to shortage of energy. It was energy deregulation. Thus, it was poor energy management that caused the energy crisis. He also stated that the current problem in North America is the growing popularity of the SUV (sport utility vehicle). The major concern is that the SUV is marketed as a normal vehicle with plenty of power rather just used for its purpose of climbing mountains. He views the SUV as an enemy. Motavalli also speculated that by the year 2010, 20 % of the vehicles on the road will be Hybrid and fuel cell vehicles. He foresees that by the year 2009, there will be 2.5 million electric vehicles on the road. This speculation caused many negative arguments. He introduced and discussed the entire topic of alternative fuels, which is summarized below along with the views of the other presenters.

As Motavalli discussed earlier, thanks to the rising fuel costs, consumers are finally looking to a more fuel-efficient vehicle instead of fuel consuming SUVs. In the month of May 2001, the sale of SUVs decreased by 13.9%. This hopefully shows the transition of consumers turning their attention toward fuel-efficient vehicles.

There are many arguments during the development of fuel cell technology. The main concerns are the explosiveness of hydrogen fuel storage tanks and the cost of production of the fuel cell's main source of fuel, Hydrogen. As for explosive hydrogen tanks, many companies already have developed a safe hydrogen storage tank, but since people have wrong ideas about hydrogen, it draws many political debates. When people hear about hydrogen, people think about the Hydrogen bomb and the Hindenberg incident. First of all, the Hydrogen bomb does not chemically explode hydrogen. Secondly, the German airship crashed because of mechanical problems. Also, people have forgotten that when

we were developing gasoline-powered vehicles, arguments surrounded the problem of the explosiveness of gasoline.

With the current technology, the cost to produce hydrogen is expensive. Unless we discover a new technology to reduce the cost of hydrogen production, fuel cell powered vehicles are unlikely in the near future.

Stuart energy and Alcan are undergoing a 12-month project and they believe the government's support is critical in R & D. Stuart Energy is trying to develop a personal hydrogen fuel cell and Alcan is developing an aluminum structure that is light and durable.

Celine Marie Lilliu from France stated that 19% of energy will be extracted from fossil fuels by the year 2020. Scientists in France predicted that the fossil fuel reserves are 960 billion barrels. Many countries will heavily depend on imported oil by 2020 except North America (58%). As for beyond 2020, important transitions can be shown. There will be a continuous growth in transport and energy demand. The WEC forecasts a 50% increase in transportation energy by 2020. The IEA predicts 75% and US DOE 80% because of the high demand in developing countries in Asia. So, IEA demands OPEC and others to increase oil production. Hopefully the cost will remain at $22.50/barrel but they are expecting costs to rise up to $28/barrel. However experts are expecting the oil price to rise continuously.

Many experts are encouraging alternative fuels since they foresee that there are only 35 years of oil left. They also believe that before 2050, transportation will use other energy sources. They projected international oil supply and demand. The result is that by 2037, the decline of oil supply is so dramatic that we have no time to make adjustments. So by 2016, a solution is required.

States such as California, Arizona and New York have already committed a large amount of resources toward research and development on alternative fuel vehicles. Most of the states have granted tax redemptions on alternative fuel purchases. In New York City, diesel engine employed Hybrid Transit buses were used in the New York Transit fleet. The passengers were very happy that the bus was quiet. Since the Americans do not take advantage of the transit system, these alternative fuel vehicles are to be used to clean the environment and attract people to use the transit service. NYC has employed 221 clean natural gas buses and 11 hybrid buses. They are expected to increase the fleet of clean natural gas vehicles by 649 and hybrid buses to 390 by 2006. Also, they are supposed to decrease diesel transit buses from 3,516 to 2,022 by 2006. As a result, the use of alternative fuel vehicles should be a success.

The price of natural gas is lower than the gasoline price. As a result, the John Deere company developed a prototype of an 8.1L, 280 hp, 900lb.ft peak of torque natural gas engine and used it in a garbage truck. The test results were better than the current diesel engine trucks. The duration of the test was 1000 hours and both types of trucks traveled the same routes. The natural gas powered truck had 2 engine/fuel system repairs, 14 others and a total of 16 repairs. As for fuel economy, the natural gas truck was 9 % better than the diesel trucks and the NOx emissions in the natural gas truck were 50% cleaner than the diesel truck.

As for the remaining vehicles on the road today, heavy-duty diesel trucks need a special emission-reducing filter. The Johnson Matthey CRT (Continuous Regenerating Technology) filter is the most advanced filter available, but is still in a development

phase. The current project is to demonstrate and test the Johnson Matthey CRT filter. The advantages of the CRT are: acceptable temperature profile; backpressure levels; NOx/PM ratio, and fuel sulfur levels are below 50 PPM. As a result, the CO, HC, and PM were reduced by 88- 98%. Also, toxic emissions such as PAH, NPAH, Carbonyls, VOC were reduced by 70 – 99%. Most importantly, PM was reduced to 99%. The remaining durability test will be completed fall 2001.

The NOx adsorber and particle filter system on light duty diesel vehicles was demonstrated. Sulfur is a toxic element that is emitted by diesel engines. There is a 12% increase in fuel efficiency in diesel but there is a penalty in using an NOx adsorber, which is 12 % power loss. The Urea-based selective Catalyst reduction technology was discussed (Urea SCR). Urea is non toxic and is also used as fertilizer. 90 % of emissions can be reduced if the diesel trucks are employed with the Urea SCR. The consequence of using Urea SCR technology is 15% power output loss. As a result, the power output loss illustrated that the NOx adsorber and particle filter system, and Urea SCR are non ideal.

The future cost of the fuel is the biggest concern for AFV developer as well as environmentalist. Even if we develop a perfect AFV, the fuel price must stay low to attract customers. EPA's 2007 regulation for emissions is extremely low. In order to meet the standards, we must work 10 times harder. The experts viewed on the EPA's 2007 regulation for emissions are rather unfeasible.

Also, political actions are crucial to the development of alternative fuel technology. For example, the AVL powertrain technology Inc. developed a Dimethyl ether (DME) engine. However, President G.W. Bush reduced funding for the greenhouse gas program. As a result, the DME powered vehicle project had to shut down from a lack of funding. Once again the political impact on AF development is crucial.

The Workshop was an opportunity for leading minds to come together to discuss issues, raise questions and concerns, and share knowledge, experiences and expertise. All the experts agreed that the fuel cell powered vehicle was considered "end of all" source of transportation. Other alternative energy sources, such as natural gas and hybrid vehicles are the interim source of transportation. I was very satisfied with the Windsor Workshop. I learned many new technologies and current issues surrounding AFV. I do agree with the experts' view in AFV, but I believe the natural gas, hybrids and fuel cell will dominate the market. Since the Canadian government is trying hard to market natural gas by adding less tax and the fuel cell will definitely be the only energy source available when fossil fuels are completely consumed.

Appendix B

Manufacturer's specifications for the Honda Insight and Toyota Prius

	2001 Honda Insight w/ AC	**2001 Toyota Prius**
Base Price MSRP (USD)	$20180	$19995
Fuel Economy (City/Highway)	61/68	52/45
Warranty	**2001 Honda Insight w/ AC**	**2001 Toyota Prius**
Basic (Months/Miles)	36/36000	36/36000
Powertrain (Months/Miles)	36/36000	96/100,000
Engine and Transmission	**2001 Honda Insight w/ AC**	**2001 Toyota Prius**
Electric Hybrid Engine	Standard	Standard
Engine Cylinders	3	4
Driveline	Front-Wheel Drive	Front-Wheel Drive
Engine Displacement (cc)	995	1497
Valve Configuration	SOHC	DOHC
Horsepower @ rpm	67@5700	70@4500
Torque @ rpm	66@4800	82@4200
Standard Transmission	Manual/Standard	Automatic
Fuel System	Multi-Port Fuel-Injected	Multi-Port Fuel-Injected
Fuel Type	Hybrid	Hybrid
Fuel Capacity (gal.)	10.6	11.9
Braking and Suspension	**2001 Honda Insight w/ AC**	**2001 Toyota Prius**
Steering System	Rack & Pinion	Rack & Pinion
Brake System (Front/Rear)	Disc/Drum	Disc/Drum
ABS Brakes	Standard	Standard
Suspension (Front/Rear)	Independent/Semi Independent	Independent/Semi Independent
Stabilizer Bar	Standard	Standard
Safety & Security	**2001 Honda Insight w/ AC**	**2001 Toyota Prius**
Airbags	Standard	Standard
Intermittent Windshield Wipers	Standard	Standard
Rear Wipers	Standard	Not Available
Vehicle Anti-Theft	Standard	Standard
Interior	**2001 Honda Insight w/ AC**	**2001 Toyota Prius**
Automatic Climate Control	Standard	Standard
Micron Air Filtration	Standard	Standard
Power Windows	Standard	Standard
Power Door Locks	Standard	Standard
Intermittent Windshield	Standard	Standard
Wipers	Standard	Standard
Clock	Standard	Standard
Front Bucket Seats	Standard	Standard
Remote Fuel Filler Door	Standard	Standard

Release		
Keyless Entry/Remote Unlock	Standard	Standard
Tinted Glass	Standard	Standard
Rear Window Defroster	Standard	Standard
Vanity Mirror	Standard	Standard
Map Lights	Standard	Standard
Cargo Area Light	Standard	Standard
Front Accessory Outlet	Standard	Standard
Tachometer	Standard	Standard
Maintenance Interval Indicator	Standard	Standard
Audio	**2001 Honda Insight w/ AC**	**2001 Toyota Prius**
AM/FM Stereo	Standard	Standard
Cassette Player	Standard	Standard
Storage	**2001 Honda Insight w/ AC**	**2001 Toyota Prius**
Coin Holder	Standard	Not Available
Beverage Holder	Standard	Standard
Seatback Storage	Standard	Standard
Exterior	**2001 Honda Insight w/ AC**	**2001 Toyota Prius**
Power Side Mirrors	Standard	Standard
Folding Side Mirrors	Standard	Standard
Dimensions	**2001 Honda Insight w/ AC**	**2001 Toyota Prius**
Curb Weight (lbs.)	1878	2728
Wheelbase (in.)	94.5	100.4
Length (in.)	155.1	169.6
Width (in.)	66.7	66.7
Height (in.)	53.3	57.6
Passenger Volume (cu.ft.,mfr.)	47.4	88.6
Cargo Volume (cu.ft.,mfr.)	16.3	11.8
Headroom (Front, in.)	38.8	38.8
Legroom (Front, in.)	42.9	41.2
Shoulder Room (Front, in.)	50.5	52.8
Hiproom (Front, in.)	48.7	50.7
Wheels & Tires	**2001 Honda Insight w/ AC**	**2001 Toyota Prius**
Alloy Wheels	14” Alloy Wheels	Standard
Tires	165/65R14	175/65R14

Appendix C

Understanding the Prius' Planetary Gear

The planetary gear allows the gasoline engine speed to be varied relative to wheel speed. If one compares the CVT (continuously variable transmission) version of the Insight to the Prius, in both cases the CVT allows the gasoline engine to run at its optimal speed regardless of vehicle speed by varying the gear ratio and it also provides smooth, stepless acceleration. However, the continuously variable transmissions in the two cars work in entirely different ways.

The Honda Insight's CVT consist of a belt and a pair of variable-diameter pulleys which are used to allow any required engine speed to wheel speed ratio.

In the Prius, a **planetary gear** is used as a power split device, providing a three-way connection between the wheels, the gasoline engine, and G (generator/motor). **The easiest way of thinking of the planetary gear is that the rotation of the wheels is always equal to the sum of the gasoline engine rotation and the rotation of G.** This means that the gasoline engine may be stationary, with any rotation of the wheels being directed towards rotation of G. It also means that if the gasoline engine is turning at a fixed speed, the faster the car is moving, the slower G will turn. In a typical driving situation, the output from the Prius's gasoline engine is split between the wheels and G. If the batteries are sufficiently charged, all energy coming from G will also be routed to the wheels, by using it to power M (motor/ regenerative braking generator). This means that power is taking two separate paths from the gasoline engine to the wheels, one entirely mechanical, and the other partially electrical.

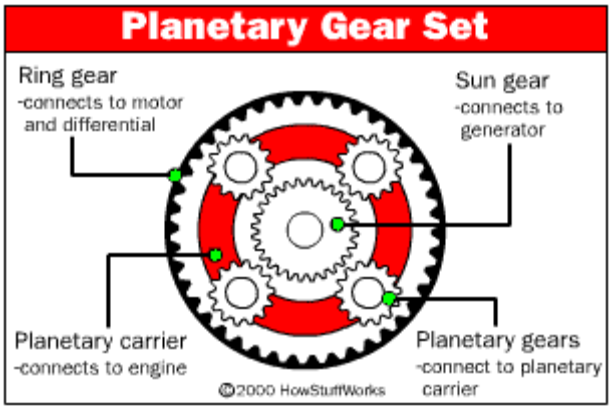

Figure 5: Planetary Gear set.

Toyota Hybrid Minivan

Toyota Motor Corporation recently unveiled a hybrid electric minivan for the Japanese market. The vehicle employs the same THS as Prius. Toyota officials said the automaker has no plans to export the hybrid electric Estima minivan, which was able to achieve 42 miles per gallon in test drives. This is about twice the mileage of the gasoline powered Estima, which has been sold in Japan, Europe and Australia, but not in North America.

This Estima is actually a Previa, which is currently sold in North America; it's also slightly narrower than a Previa, to accommodate Japan's city and road tax conditions.

Toyota said the hybrid electric Estima will sell for between 3.3 million yen (about US$27,000) and 3.6 million yen (US$30,000). The vehicle delivers electric power, parked or in motion, and has electric sockets for hair dryers, laptops or microwave ovens.

Appendix D

The staff of Ontario Ministry of the Environment West Central Region's evaluation of Honda Insight.

As you know, I've had the opportunity to drive the Insight on a few occasions. I found it to be very comfortable to drive even though I'm 6'2. Beyond that, I think driving the Insight to inspections/complaints showcases the vehicle to the public. I think that all government agencies, including the M.O.E. should be openly endorsing the Insight or similar hybrid electric vehicles, especially in the city of Hamilton, where air quality has been and continues to be an issue.
Jason Ryan

I have found the Honda Insight a most enjoyable car to drive. Reliability has been very good, with one exception (for me), when the car required a warranty repair.
The car has excellent acceleration, stability and maneuverability, both in city and in highway driving. Visibility is good. Trunk space is smaller than an average sedan, but, with the large secret compartment, was very adequate for normal use, going to meetings, etc. In fact I took the car to Eastern Ontario for a three-day meeting/workshop and there was lots of room for briefcase, meeting material, luggage, etc.
The vehicle has superb efficiency, obviously, as a hybrid vehicle, and there are significant cost advantages due to this, as well as the reduction in air pollution and, of course, the convenience of less stops for refueling.
The anti-idling feature (engine turns off automatically when stopped and then restarts when the car is put back in gear) is a welcome addition that cuts down on local air pollution as well as adding to overall efficiency.
Dashboard layout is very clear and even interesting, with the electronic display showing when the battery assembly is charging or recharging.
Denis Corr

I'm disappointed that the car is mostly powered by gasoline, and the batteries play a very small part.
Tina Dufresne

Evaluation from Mr. John Noble, fleet manager, Hamilton Hydro.

Insight

Likes	Dislikes
User friendly Quiet operation Sporty appearance	Rear vision Exterior Standard gear No cruise control 2 seater trunk space acceleration unstable driving conditions resulting from hard tires

-Sport appearance but forces you to drive like a fuel economy car.

Prius

Likes	Dislikes
Acceleration Plenty of room for 5 Ventilation system Sound system Trunk space Winter driving condition was very satisfying	Stereo not user friendly Seats Leg room Braking

Place for improvement

- Stereo control on a driving handle.

Appendix E

Comments from the Insight Central website.

These are the actual owners and U.S. residents

Mar 25, 2001 - Patti Obana-Winkle - "Accord LX ... gas bill was $300/month ... Insight ... under $100/month"

Pros	Cons
Fun to drive! Fuel economy $2000 tax deduction from IRS!	Blind spot in passenger rear side Getting stuck in deep road ruts and Muni (bus) rails

Feb 12, 2001 - Mike Cohen - "I am now completely SUV (CRV) free and loving it"

Pros	Cons
Handling Gas Mileage Comfortable Seats Incredible Looks	4 people a day asking what it is Rear view mirror is way too small Stereo power Not a big enough battery to run a amp and subs

Feb 10, 2001 - Steven - "The Honda Insight ... is my first car and I really love it. "

Pros	Cons
Fun Sporty cockpit Digital display Sporty suspension Nice interior	won't be racing vipers anytime soon :P

Jan 12, 2001 - Thomas Pfarr

Pros	Cons
The ultimate Geek Mobile. As an engineer I love everything about it, design, technology, practicality, build quality. Just amazing.	MY 1960 RAMBLER HAD BETTER SPEAKERS. This had to have been a joke from the engineering staff right?

Jan 10, 2001 - David P.

Pros	Cons
great fuel mileage and good performance great 'citroenesque' aero shape	why? why? just a few more inches and they could have squeezed out a four-seater!! how about devoting a bit of the technology to ride quality in the way of two settings, and sound insulation. get ready to go stereo shopping

Dec 17, 2000 - George & Grace - "We decided it was time to stop talking about doing something about our impact on the environment"

Pros	Cons

Great Fuel Efficiency Low Emissions Fun To Drive Great conversation starter to educate peoples about environmental issues, and what we can do as individuals and as a society.	Speaker Audio Quality is Awful! No Cruise Control

Andy Mattson - "I gave up my BMW 3-series for this, and I have no regrets"

Pros	Cons
Great handling Convenient Fantastic MPG Roomy	Crappy Speakers Don't get stuck with green

Brian Pirie - "I'd buy it again in a heartbeat"

Pros	Cons
Lots of fun to drive Amazing efficiency Size & format Clean operation Aluminum construction Ingeniously simple implementation of hybrid powertrain	Road noise at higher speeds The speakers Come on, who wants a cassette player? Have had a number of squeaks and rattles to fix

Elizabeth Knight - "My husband is jealous that ... I get to drive it most of the time"

Pros	Cons
Mileage (of course)	Handling on rutted roads Dashboard display brightness

Lafayette, Colorado USA

Geoff Shepherd - "Had that Insight-grin going on all the way home"

Pros	Cons
Extremely Fuel Efficient Performs Well Usable storage under hatch Fun to Drive Well Equipped Fascinating Technology Long Range Quiet Speakers/Stereo a snap to replace Beautiful body design and paint job LCD dash very readable even in bright sunlight	Stock speakers poor Carpet wears easily – floor mats are a must Seat upholstery frays if contacted by Velcro fasteners such as on "parachute pants" Road noise very noticable on poor pavement (but still a quiet car overall) Deeply worn highway ruts can toss the car around a bit Goofy grin while driving

Lots of low-end torque makes scooting around the city and climbing hills effortless Idle-stop makes for absolute silence at intersections Virtually seemless driving Experience	

Hank Bennett - "Seeking to improve my 'lifetime MPG' is fun and rewarding. This is one smart car."

Pros	Cons
Fantastic design Quiet Spunky Comfortable great Climate Control Proper luxuries without excess.	Speakers Would like to raise driver's seat tilt about 1 inch forward

Phil Bracewell - "I traded my '98 Camaro SS for my Insight."

Pros	Cons
Great mileage Fun to drive Quick Quiet Conversation starter	Speakers and stereo Blind spots on rear corners

Tim Drager - "I bought it right on the spot"

Pros	Cons
Quiet Fun Attention	N/A

Appendix F

The following are generated by M. Cho and respondents from the Yahoo Group.

Polls Polls Help

Question

What was your motive for purchasing Toyota Prius?

Responses

Choices	Votes	%	300 replies
To improve the environment	96	32.00%	
Rising cost of fossil fuel	44	14.67%	
Appearance (Interior and Exterior)	11	3.67%	
Facination of the Technology	99	33.00%	
Overall performance (quiet, handling, acceleration, etc...)	25	8.33%	
Reliability	19	6.33%	
Other	6	2.00%	

Question

What was your motive for purchasing Honda Insight?

Responses

Choices	Votes	%	98 replies
Facination of the Technology	22	22.45%	
To improve the environment	18	18.37%	
Because of rising cost of fossil fuel	27	27.55%	
Sporty appearance (Interior and Exterior)	8	8.16%	
Overall performance (quiet, handling, acceleration, etc...)	10	10.20%	
Reliability	8	8.16%	
Other	5	5.10%	

Question

What is your lifetime mileage?

Responses

Choices	Votes	%	71 replies
38 or less	1	1.41%	
39	0	0.00%	
40	3	4.23%	
41	5	7.04%	
42	6	8.45%	
43	7	9.86%	
44	11	15.49%	
45	5	7.04%	
46	11	15.49%	
47	2	2.82%	
48	2	2.82%	
49	4	5.63%	
50	6	8.45%	
51	2	2.82%	
52	3	4.23%	
53	1	1.41%	
54	1	1.41%	
55	0	0.00%	
56	0	0.00%	
57	0	0.00%	
58	1	1.41%	

Poll created by kamus member.

Question

What's your general level of satisfaction with your Prius?

Responses

Choices	Votes	%	199 replies
Totally jazzed	152	76.38%	
It's pretty cool	44	22.11%	
It's just OK	1	0.50%	
I'm a little disappointed	2	1.01%	
I've got buyer's remorse	0	0.00%	