Alternative Fuels

a guide to

The Charleston Documentary Film Festival
ChasDOC, inc. PO BOX 14097 Charleston, SC 29422
www.chasdoc.org info@ChasDOC.org
843. 277-0485 (t) 843. 277-1422 (f)

Alternative Fuels

Liquefied Petroleum Gas (LPG)

Fuel Source

Liquefied petroleum gas, as the name suggests, is partly a byproduct of petroleum refining; in California the state's oil refineries are the main source, but nationwide well under half of LPG comes from petroleum refining, and the rest from natural gas processing. It consists of hydrocarbons that are vapors, rather than liquids, at normal temperatures and pressures, but which turn liquid at moderate pressures; its main constituent is propane, and it is sometimes referred to by that name.

Wholesale Availability

Since everything from barbecue grills to portable heaters runs on LPG, and since it is used for home heating in rural areas where natural gas pipelines don't run, there is an extensive distribution network nationwide, and has been for many years.

Retail Availability

See above; LPG is easy to find. It may be expensive if you buy it from a retailer who's used to filling five-gallon barbecue-grill bottles, but there are lots of places that will sell you automobile-sized fill-ups at a lower price per gallon.

Advantages

Because it's so widely available, LPG is the least "alternative" of alternative fuels if "alternative" equates to inconvenience, and most of

the alternative fuel used in the United States is LPG. (One might also say, given LPG's dominance of the alternative-fuel market, that it's the *most* alternative fuel...) In order to liquefy the fuel, it is stored in sturdy tanks at about 20 times atmospheric pressure; since these are much tougher than typical sheet-metal or plastic gasoline tanks, and since they have a built-in shutoff valve to seal the tank if the fuel lines start leaking, LPG is safer than gasoline. (The tanks are a permanent part of the vehicle, unlike barbecue-grill tanks, so they are immune to the usual cause of LPG fires, which is leakage due to the operator's failure to hook the tank up properly.) It is also somewhat cheaper than gasoline in most places at most times, when you compare the price of a gallon of gasoline with the price of the somewhat larger volume of LPG needed to drive the same distance.

Because LPG enters the engine as a vapor, it doesn't wash oil off cylinder walls or dilute the oil when the engine is cold, and it also doesn't put carbon particles and sulfuric acid into the oil. Thus an engine that runs on propane can expect a longer service life and reduced maintenance costs. (Incoming liquid gasoline cools the combustion chamber and valves as it vaporizes, so you might expect, for example, that you'd need a valve job more often on an LPG-burning engine because the gaseous fuel doesn't give this cooling effect. However, modern valve and valve-seat materials, designed for unleaded gasoline, don't have problems with the "dry" fuel. More recently, direct injection of LPG in the liquid state, with attendant cooling effect as well as improved emissions control, is being tested.) Its high octane rating (around 105) means that power output and/or fuel efficiency can be increased, without causing detonation ("knocking"), in a vehicle that isn't required to run on gasoline as well.

Disadvantages

LPG is, again, in some ways the least "alternative" of alternative fuels; because its source is partly petroleum, it does less to help relieve the petroleum dependency problem than some other alternative fuels, and given the dominance of the petroleum source in California it is not even considered an alternative fuel for some state incentive programs. On the other hand, nationwide about 90% of LPG is domestically produced (even if a fraction comes from an

imported petroleum feedstock), and most of the remainder comes from Canada (which is a heck of a lot more stable than the Mideast!), so LPG does help to remedy the national security component of the overall petroleum dependency problem.

Its somewhat lower energy content compared to gasoline means you need a slightly bigger tank to get the same driving range; the tank will also be heavier because it has to be strong enough to withstand the LPG storage pressure. Mostly because of the special fuel tank, a vehicle that runs on LPG will typically be somewhat more expensive (around $1000-2000) than an equivalent gasoline-powered vehicle. Finally, the refueling procedure on an older-style tank (evolved from that for filling grill bottles) involves the release of some raw fuel vapors (unburned hydrocarbons) into the air, though these are much less reactive (have less "ozone-forming potential") than gasoline vapors; however, I understand that modern propane tanks, and the dispensers that fill them, are designed to eliminate most of this spillage.

Compressed Natural Gas (CNG)

Fair warning: I am much more familiar with CNG than with any other alternative fuel, having owned and driven vehicles that use it since 1993. So you might want to de-weight some of the extra enthusiasm I show on this page relative to other fuels!

Fuel Source

Natural gas is, well, natural gas--the same stuff that heats your stove or your house. It is largely produced domestically in the United States; it can be imported through pipelines or as a cryogenic (super-cold) liquid on special tanker ships, but because this is a lot harder than pouring crude or refined oil into a tanker or a pipeline, we haven't built up an import dependency for natural gas as we have for petroleum. (Interest in imported natural gas is growing, however, as domestic production has lagged behind increasing demand for this

clean fuel.)

Wholesale Availability

Natural gas is distributed nationwide through an extensive network of pipelines, which feed electrical generation plants and domestic and industrial heating uses. Thus the use in vehicles of natural gas is "piggybacking" on many years of infrastructure development.

Retail Availability

In order to store a reasonable amount of fuel (*i.e.*, enough to drive a reasonable distance before refueling), natural gas has to be compressed to around 200 times atmospheric pressure--or even more for the tanks aboard large buses! This is like the pressure a mile and a quarter under the ocean, and requires special compressors to be "tapped into" the pipelines. When I bought my first CNG-powered vehicle in late 1993, I had to drive 35 miles roundtrip to the nearest public refueling station; now there is a station less than two miles from my job, so these refueling stations are becoming more common, and not just in Southern California. There are enough nationwide now that I was able to drive Clean Across America And Back in August 1998! In addition, there are home refueling appliances (from FuelMaker Corp.) now available that tap into your domestic natural-gas and electrical lines and slowly refuel your vehicle overnight, so you wouldn't need to use public refueling stations very much at all if you typically drive less than one or two hundred miles a day.

Advantages

Compressed natural gas is like liquefied petroleum gas (LPG) in many ways, only more so. It is very easy on the engine, giving longer service life and lower maintenance costs. CNG is the least expensive alternative fuel (except electricity) when you compare equal amounts of fuel energy, and, in my experience at least, its price has been relatively steady (except for one big jump when California utility regulators changed the rules!). At the peak of the big gasoline price run-up in April, 1996, I was paying half as much for a gasoline-gallon-equivalent of 130-octane natural gas as I would have paid for

a gallon of 92-octane unleaded gasoline! Even with the natural-gas price spikes of the last few years, I have found the price of CNG to be less volatile, and on average lower, than that of gasoline.

The high octane rating of natural gas allows the CNG-powered Honda Civic GX to use a very high compression ratio and produce more power than stock gasoline versions. My own van has a stock compression ratio and about 10% lower power output than the gasoline version with the same-size engine, but I get significantly better fuel economy on the open road because the high octane rating of the fuel allows timing and mixture to be adjusted for more efficiency without causing detonation ("knocking"). And, as with LPG, because the fuel tanks have to withstand such enormous internal pressures, they are incredibly tough, with good results for safety. In addition, because natural gas is lighter than air and has very narrow flammability limits, if a leak develops it is very likely that the fuel will dissipate harmlessly into the air without causing a danger of ignition or explosion.

Natural gas has, over the course of the 1990's, proven to be the most effective fuel for reducing emissions in an internal combustion engine. The 1993 Dodge full-size CNG vans like mine were the first vehicles to meet the California Low Emission Vehicle (LEV) standards; the 1994 Chrysler/Dodge CNG minivans were the first to meet the Ultra-Low Emission Vehicle (ULEV) standards; the 1997 Ford CNG pickups and vans were the first to meet the Super Ultra-Low Emission Vehicle (SULEV) standards; and the CNG Honda Civic GX has been the cleanest internal-combustion-engine vehicle ever tested by the EPA in every year since its 1998 introduction. There are now a fair number of gasoline-powered vehicles that run cleaner than my van, but it took five years for the first gasoline vehicle to catch up (with a much smaller engine than my van's!), and in the meantime natural-gas-vehicle emissions have continued to plummet.

Disadvantages

Again, CNG is like LPG, but more so. The tanks are quite bulky and heavy, about three times more so than LPG tanks (have a look at the photos of my van--the tanks are half-inch-thick aluminum clad with

reinforced fiberglass), though modern composite technology is starting to be used to cut weight and cost (as on the Honda Civic GX). Range is significantly less than for an equivalent gasoline vehicle, unless you really go overboard adding extra fuel tanks! And again, mostly because of the heavy-duty tanks, there is currently a large price premium for a CNG vehicle compared to a gasoline version ($3000-5000). The fuel and maintenance costs can be enough cheaper, however (like the first time you *don't* have to spend $2000 to overhaul the engine!), in a high-mileage application like a transit bus, a taxi, or a shuttle van, that this will repay the higher initial purchase price over time (and, depending on where you live, you can piece together enough federal, state, and local incentive money to cover most of the extra purchase cost in the first place--this was true for me). Finally, the refueling infrastructure is still growing, as noted above.

Liquefied Natural Gas (LNG)

Fuel Source

Liquefied natural gas for vehicles comes from the same sources as compressed natural gas (CNG), or for that matter as the gas that cooks your dinner. Unlike liquefied petroleum gas (LPG), which is changed from a vapor to a liquid at room temperature by application of pressure, LNG has to be cooled to very low temperatures in order to cause it to liquefy; this makes it hard (though not impossible) to transport via tanker, and it is usually liquefied at the dispensing station.

Wholesale Availability

As with CNG, LNG benefits from decades of infrastructure development because of heavy domestic, industrial, and utility use of natural gas.

Retail Availability

LNG is somewhat behind CNG in retail availability, because of the added complexity of a cryogenic (ultra-cold) liquefying station compared to a compressor station. However, there are projects being undertaken (like the Clean Cities Corridors program) to construct enough refueling stations along major trucking highways to allow LNG-powered long-haul trucks to replace diesels along some routes. Also, individual local delivery fleets are building their own stations for central refueling so that they don't have to worry about publicly-available facilities.

Advantages

LNG has all the emissions advantages I bragged about for CNG. In addition, the liquefaction process amounts to a distillation, so the fuel is essentially pure methane (CNG can contain up to 12% of heavier molecules in California, like ethane and propane, and even more elsewhere), which prevents variations in fuel quality that I'm told can occur for CNG (or gasoline, for that matter). Also, LNG is a somewhat less bulky and heavy way to store natural gas than as CNG in high-pressure tanks.

Disadvantages

Though LNG tanks are less bulky and heavy than CNG tanks, they are still more so than tanks for liquid fuels like gasoline, diesel, or alcohols. They are also more complex and expensive because they have to insulate the fuel very well in order to prevent it from warming up and boiling off too fast. Even with modern, rocket-science (literally!) insulation materials and techniques, a LNG tank will begin venting fuel if left to sit for several days, so the fuel is best used in high-duty-cycle applications like delivery trucks.

Methanol (M85)

Fuel Source

Methanol is typically made from natural gas; though it is possible to produce it by fermenting biomass (this is why it is sometimes called "wood alcohol"), this is not economically competitive yet. Because it is easier to transport natural gas to a distant market by converting it to methanol, which is a liquid at ordinary temperatures and pressures, than by chilling and liquefying it or by building a long pipeline, some petroleum-exporting countries are looking at exporting their "waste" natural gas (which they currently "flare off" in huge flames visible from the Space Shuttle!) by converting it to methanol; however, most of the natural gas that goes into methanol in the United States is still domestically produced. For reasons to be explained below, most fuel methanol in this country is sold as a blend of 85% methanol with 15% unleaded premium gasoline, whence "M85". In the not-too-distant future, "neat" (100%) methanol may be the preferred means of storing hydrogen for fuel-cell electric vehicles, but this technology is still in the R&D stage.

Wholesale Availability

There have been efforts to introduce M85 into various fuel markets, notably in California, but there is no nationwide transportation network in place for this as a bulk fuel (on the scale of gasoline, diesel fuel, or natural gas) yet. The methanol industry's efforts to enter the transportation fuels market recently have been largely focused on a derivative compound called methyl tert-butyl ether (MTBE), an additive used in oxygenated gasoline, though concerns about water table contamination have caused this to lose favor.

Retail Availability

There are still not very many M85 stations in the United States. However, only relatively small changes need to be made to a gasoline fueling station (linings and seals in tanks, pumps, dispensers, ...) in order to handle M85, compared to the completely new construction needed to handle compressed or liquefied natural gas (CNG or LNG) or liquefied petroleum gas (LPG), so M85 capability can be added in a big hurry if local governments, consumers (usually fleets), and retailers decide to develop a market.

Advantages

Alcohol fuels like M85 are perhaps the most "transparent" alternative fuels to the user, *i.e.*, they are the least distinguishable from gasoline in how you buy and use them, which should ease acceptance. The fuel system of a car or truck only needs to be slightly changed (somewhat different materials, bigger fuel injectors, and a fuel composition sensor) in order for it to run on M85, and recently automakers have been offering M85 vehicles at no extra cost over their gasoline counterparts (or even for slightly less money), though at present automakers seem to be more interested in ethanol (E85). At least in California, the fuel costs about the same per mile as mid-grade gasoline (that is, you need about 1.7 gallons of M85 to get the same driving range as one gallon of gasoline, but price of a gallon of gasoline is about 1.7 times the price of a gallon of M85, so it balances out). And perhaps best of all, modern M85 vehicles are flex-fuel vehicles, which means that any mixture of M85 and gasoline in the fuel tank can be used by the engine; a fuel-composition sensor tells the engine computer what percentage of methanol is in the fuel, and it adjusts the injectors and ignition accordingly. Thus an M85 vehicle *is* a gasoline vehicle if M85 is not available, but you can top it off with M85 whenever you get back into an area where it can be found, and you don't have to carry (and pay for!) two separate fuel systems to do this.

Disadvantages

Methanol is more corrosive than gasoline (though it is less toxic, and not carcinogenic); this is why an automaker needs to change some of the materials in the fuel-handling systems of both the vehicle and the refueling station to materials that can withstand attack by the fuel. Special oil additives are necessary in order to protect the engine. Also, because the mixture of air to fuel is much richer than gasoline (about 8 to 1 by weight, compared to about 14 to 1 for gasoline), there is more liquid fuel available to wash oil off of cylinder walls during a cold start. Some early methanol users experienced durability problems, but development work has been making steady progress.

The richer fuel/air mixture needed by methanol also means that a given volume of gasoline will take you about 70% farther than the same tank full of M85; most automakers have at least partially compensated for this by putting a larger fuel tank in their M85 vehicles. And the reason that methanol is most commonly used in a mixture with 15% gasoline is to correct for two disadvantages of pure methanol. One is that a methanol flame is colorless, so gasoline is added to give the flame some color so rescuers can tell if a fire is present should an M85 vehicle get into a crash. The other is that methanol, being a pure chemical compound, has a single boiling point, so that it can cause cold-start problems in cold weather, or vapor lock in hot. Gasoline, being a mixture of compounds with different boiling points, always has some components that want to stay liquid and some that want to vaporize at a given temperature, so adding it to methanol confers this flexibility on the M85 mixture. Indeed, some manufacturers recommend mixing additional gasoline with M85 in very cold weather.

Ethanol (E85)

Fuel Source

Ethanol, or grain alcohol, is produced by fermenting biomass, commonly corn (though other, lower-value feedstocks have been tested in an effort to reduce costs, like brewery waste and cheese-factory effluent--blecch!). It is thus inherently a renewable resource, and contributes nothing in itself to greenhouse-gas loading of the atmosphere (and with efficient modern farming techniques, there's still an improvement even when you add in the petroleum-based fuel burned to plow the fields, make the fertilizer, etc.). As an alternative motor vehicle fuel, it is usually blended in a mixture of 85% ethanol, 15% unleaded gasoline, whence E85. (It is also used in up to 10% blends with gasoline (gasohol) to oxygenate the gasoline, and this mixture can be used by most modern gasoline vehicles.)

Wholesale Availability

E85 is, in many ways, like M85, the other alcohol fuel made with methanol instead of ethanol blended with 15% gasoline. There is no national distribution network on the scale of those for gasoline, diesel, and natural gas; however...

Retail Availability

...there are starting to be a fair number of E85 outlets, mostly in the Midwest (where the crops from which ethanol is made are grown), and the changes needed to enable a gasoline station to handle E85 are even smaller than those necessary for M85. Elsewhere in the nation, E85 stations are rarer than M85 stations; in particular, I don't think there's a single one in California.

Advantages

Ethanol, as noted above, is a renewable resource that contributes nothing in itself to global warming concerns. Like methanol, it can be blended with any amount of gasoline in the tank of a flex-fuel vehicle, which is what automakers are selling these days. In fact, starting with the 1999 model year, some automakers are making *every one* of certain vehicle models capable of using E85 in any mixture with gasoline, at no extra charge. Thus buyers will not have to do anything extra at all to have a vehicle capable of using an alternative fuel, though they will still have to find an E85 fueling station to take advantage of that capability.

Disadvantages

The main disadvantage of E85 is the price of the fuel, even with the available subsidies. However, research is under way to enable the fermentation of lower-grade feedstocks (think of using not only the corn squeezin's but also the cob to make alcohol!), which should help a lot. Ethanol is somewhat corrosive, though less so than methanol, and concerns about vapor lock, cold starts, and flame visibility like those for methanol have led to the same standard blend of 85% alcohol with 15% gasoline.

Biodiesel (B20)

Fuel Source

Biodiesel is to petroleum diesel fuel what ethanol (E85) is to gasoline: a substitute fuel made from biomass, which means that it is inherently renewable and, in itself, it contributes nothing to carbon-dioxide loading of the atmosphere. Biodiesel commonly uses soybean or canola oil as its base, but animal fat or recycled cooking oil can also be used. To speed its market introduction, and dilute its additional cost over petroleum diesel fuel, the initial commercial product being studied is a blend of 20% biodiesel and 80% petroleum diesel fuel, whence B20.

Wholesale Availability

Biodiesel is not currently widely available, though production-scale plants (as opposed to laboratory-scale experimental setups) do exist, for example NOPEC.

Retail Availability

See above; you can't buy biodiesel readily yet, though retail stations are starting to appear. However, B20 requires absolutely no change in the storage or dispensing hardware that handles petroleum diesel fuel, and even "neat" biodiesel (or "B100") would only require minor changes in some materials used for seals, hoses and the like. Thus the retail infrastructure for a B20 market is *already* in place. (It's also possible to burn straight vegetable oil (SVO) in a diesel engine, either "virgin" or used (french-fry grease!), but this requires an extra tank for the fuel and the engine has to start and warm up on regular diesel fuel. However, you may be able to get waste vegetable oil from a local restaurant for free!)

Advantages

As noted above, B20 can be stored and dispensed in exactly the same manner as petroleum diesel fuel; in addition, diesel-powered vehicles require no modification at all to run on B20 or even higher blends. Thus any diesel-powered truck or bus is, potentially, already an alternative-fueled vehicle! For example, an ordinary used Winnebago was "converted" into the Veggie Van simply by pouring homemade biodiesel into its tank. Since biodiesel is not a fossil fuel, as noted above, it can cut greenhouse-gas emissions as well as ordinary pollutants (particularly soot) by displacing petroleum diesel fuel.

Disadvantages

The main disadvantage of B20, like that of E85, is fuel cost. However, since it requires no changes in hardware (vehicle or refueling) or retraining of mechanics and users, studies have shown that it could be the most cost-effective way for some fleets to meet clean-air requirements (compressed natural gas cuts fuel and maintenance costs, but vehicles must be replaced or converted to use it, and mechanics must be retrained, which may tip the balance).

Electricity

Fuel Source

Electricity can be made by many means, from the burning of high-sulfur coal to pollution-free photovoltaic cells (or solar cells). Electric vehicles are generally divided into battery and hybrid classes, depending on whether the electricity is generated off-board and stored in a battery or generated by a small on-board powerplant. Hybrid electric vehicles can be designed to run on any fuel, including gasoline or diesel as well as alternative fuels, and can best be thought of as highly-efficient gasoline, diesel, or alternative-fueled vehicles. This page discusses battery-electric vehicles, whose power comes from an off-board generator somewhere.

Wholesale Availability

Electricity is the most readily available form of energy in the United States; the network of power plants and transmission lines reaches even where natural-gas pipelines don't.

Retail Availability

Since electricity is available virtually everywhere, "retail" electricity for refueling (recharging) is ubiquitous--*if* you have the right kind of socket into which to plug your vehicle. Conventional cars converted to run on electricity usually are built to plug into ordinary 110-volt wall sockets and/or 220-volt appliance outlets, but modern production electric vehicles are mostly being built with specialized connectors that can speed up the "refueling" process and increase safety. You can install a recharging station with the right kind of connector for your vehicle in your garage, and in some cities recharging stations that offer the most popular connectors are being installed in public places (and in all the cases I know of, recharging at a public station is free!).

Advantages

Electric vehicles have the potential to be by far the cleanest means of transportation, and even in the near term it takes a very advanced natural-gas-powered vehicle like the Honda Civic GX to give them a run for their money in terms of low pollution. The reason is twofold. First, electric generators and motors are very efficient; even accounting for losses in producing electricity from some fuel, transmitting it over power lines, recharging a battery with it, and feeding it out of the battery to the motor, you still can go a lot farther by burning a given amount of fuel to generate electricity for an electric car than by using it directly in an internal combustion engine. Moreover, the same electric motor that expends energy to speed a vehicle up can be run as a generator to absorb energy and slow the vehicle down; this is called regenerative braking, and it allows energy to be recovered and put back into the battery that, in a conventional vehicle, simply gets wasted as heat in the brakes. Thus, to go a given distance, you will burn a lot less fuel and generate a lot less pollution

if you use it to generate electricity for an electric vehicle than if you use it in a conventional internal-combustion powertrain.

Second, electric generation is generally done in the cleanest possible manner for a given fuel, and power utilities keep their generators in top condition as a matter of course (I can't afford to get my van's engine tuned up every week, can you?). It is true that charging an electric vehicle from the power mix in some parts of the country results in replacing gasoline in the car with coal in a powerplant, which generally burns dirtier, as the power source; however, modern coal-burning powerplants are a lot cleaner than they used to be, and accounting for the efficiency with which the energy is used, you still come out ahead in almost all pollutants. Moreover, electric generation is getting cleaner all the time: as time goes on, older, dirtier generating plants are being taken out of service and replaced with newer, cleaner ones, or even with pollution-free solar or wind generators. Thus an electric car will get cleaner over time as the powerplants from which it gets its energy are upgraded, and it can switch to fully renewable energy sources without a hiccup as they come online; by contrast, a conventional car, or even one that runs on natural gas, methanol, or another alternative fuel, will get dirtier over time as its catalytic converter and other emission-control features age.

To put some numbers to the above discussion, I will note that the California Air Resources Board has calculated (see Table 9-3 on page 137 of a 2000 staff report) that a battery electric vehicle recharging from the California utility power mix will produce about 98% less pollution than an average 2002 model car over their respective lifetimes, and 95% less pollution than even the cleanest 2002 car--hybrid, PZEV, you name it. For this reason, they have long maintained that vehicles running on electricity, or other fuels like hydrogen that emit zero tailpipe pollution, are the "gold standard" for meeting air-quality goals.

Electric vehicles are by nature low-maintenance, and their simplicity (an electric motor has one moving part, the rotor, in contrast to how many in an internal combustion engine?) means that, when produced in large numbers, their price should be low compared to other vehicles (look how inexpensive and how common electrical appliances and tools are). As long ago as the May 30, 1994 issue of

Business Week, I read that Chrysler thought they could produce an electric vehicle for the same price as a gasoline vehicle in volumes of 300,000--that's a small number for a major automaker. This price comparison didn't include the batteries, but electricity is so cheap compared to any other fuel that, as prices of battery packs come down, the savings in fuel and maintenance would more than pay for them.

Disadvantages

The biggest *real* disadvantage of electric vehicles, at present, is their higher price; even today, though, if you need a vehicle to do a lot of stop-and-go driving and idling, which wastes a lot of fuel and is *very* hard on an internal combustion engine, you can save enough in fuel and repairs to make an electric vehicle pay for itself even without the substantial tax credits and other subsidies that are available. This kind of driving is typical of city delivery vans, and, come to think of it, of a lot of urban commuting... Anyway, modern electric vehicles have been built only in extremely small numbers--hundreds, not hundreds of thousands, per year--so economies of scale have not even begun to come into play to bring their prices down.

The biggest *perceived* disadvantage of electric vehicles is their range. Modern freeway-capable electric vehicles have ranges between recharges of perhaps 60 to 120 miles, which won't get you very far down the interstate (unless you are willing to take time to stop and recharge frequently, like Kris Trexler on his Charge Across America). But many people, including myself, would say this is not a real disadvantage because, realistically, how often do most people drive over 60 miles in a day? Even the lower end of modern electric vehicles' range is enough for most people's daily commuting trips, even where I live in Southern California, and since an electric vehicle can be recharged overnight (usually at cheaper electric rates than during the day, too!) while parked in your garage, all you really need to be able to carry in the "fuel tank" is enough electrical charge for one day's use.

An analogy with a microwave oven is often made by electric vehicle advocates: when they first came out, microwave ovens were derided because they couldn't, for example, cook a Thanksgiving turkey. But

how often does one need to cook a Thanksgiving turkey? Which do *you* use more often, your microwave or your conventional oven? If, in a typical two-car family, one of the two cars was replaced by an electric vehicle, it wouldn't become the "second car": it would be cheaper to use it as the primary car, for the vast majority of commuting, errands, and other driving duties. The conventional car would only be put into service like the conventional oven: on special occasions. (Okay, so maybe my use of this analogy was colored by the fact that, when I wrote it, I was a bachelor and lived on frozen dinners, using my conventional oven and dishwasher mostly for storage...)

But, for those still concerned about range between recharges, advanced batteries like the nickel metal-hydride ones in my digital camera have already been put in modern electric vehicles like the Honda EV Plus and the GM EV1, and even more advanced ones like the lithium-ion pack in my portable computer are being developed; both of these will extend driving ranges compared to the inexpensive but low-capacity lead-acid battery. Also, high-powered quick chargers that can "refuel" an electric vehicle's battery pack in minutes rather than hours have been tested.

Hydrogen

Fuel Source

Hydrogen does not occur free in nature; it can be made by "re-forming" natural gas or another fossil fuel, or by using electricity to split ("electrolyze") water into its components of oxygen and hydrogen. In this sense, hydrogen is like electricity: the energy to generate it can be obtained from sources ranging from the burning of high-sulfur coal to pollution-free photovoltaic cells (solar cells).

Wholesale Availability

There is not currently a bulk hydrogen distribution infrastructure on

anything like the scale of that for fossil fuels, though studies have been undertaken of the possibility of sending it through the existing natural-gas pipeline network (with some substantial modifications). Because hydrogen can be made from natural gas by re-forming or from water by electrolysis, and natural gas, electricity, and water are readily available, it might be simpler to make the hydrogen at the point of sale, rather than ship it there.

Retail Availability

See above; hydrogen is currently available only as an industrial or scientific chemical product, not as a bulk fuel.

Advantages

Hydrogen has been called the "most alternative" of the alternative fuels: if it is made by electrolysis of water using electricity from a nonpolluting source like wind or solar power, then no pollutants of any kind are generated by burning it in an internal combustion engine except for trace amounts of nitrogen oxides, and if it is used in a fuel cell then even these disappear. Furthermore, no greenhouse gases are generated because there's no carbon in the fuel. All that comes out the vehicle's exhaust is drinkable water! Using hydrogen as the "battery" to store energy from a nonpolluting, renewable source would result in a truly unlimited supply of clean fuel. The advantage of using hydrogen to store energy rather than a battery pack is that a hydrogen tank can be refilled in minutes rather than recharged in hours, and it takes less space and weight to store enough hydrogen to drive a given distance on a single refueling than it does to carry enough battery capacity to go the same distance on a single recharging. The battery-electric drivetrain uses energy more efficiently, and can handle the vast majority of daily commute-and-errands driving that people do, but for long trips hydrogen could prove to be a lot more convenient.

Disadvantages

Hydrogen is currently very expensive, not because it is rare (it's the most common element in the universe!) but because it's difficult to

generate, handle, and store, requiring bulky and heavy tanks like those for compressed natural gas (CNG) or complex insulating bottles if stored as a cryogenic (super-cold) liquid like liquefied natural gas (LNG). It can also be stored at moderate temperatures and pressures in a tank containing a metal-hydride absorber or carbon adsorber, though these are currently very expensive. It is possible to store a hydrogen-bearing fuel like natural gas, methanol, or even gasoline aboard the vehicle and re-form it to get hydrogen as needed; this simplifies storage and refueling, but adds cost and complexity to the drivetrain (and reduces efficiency). It is not a very good fuel for an internal combustion engine, being prone to preignition, though BMW, Mazda, and Ford have done some tests; the most efficient way to use it is in fuel cell vehicles, but these are still in the demonstration stage.

Under "Advantages" above, I discussed the benefits of using hydrogen generated from renewable, nonpolluting power like solar electricity. However, as hydrogen fuel has gained political momentum, concern is growing that the inefficiencies of generating, transporting, and storing hydrogen may make it a poor choice if the energy used to generate the hydrogen comes from fossil fuels (whether via re-forming those fuels directly, or by burning them to generate electricity for electrolysis of water). It is definitely more efficient to generate electricity from a fossil fuel, transport it via wires, and use it to charge up a battery-electric vehicle than it is to burn the same fossil fuel in an internal-combustion engine aboard a conventional vehicle; however, it is uncertain whether it is more or less efficient to use that fossil fuel to generate hydrogen for use in a vehicle. If the hydrogen is produced at a central plant, there are inefficiencies associated with generating it, transporting it via truck or pipeline, and storing it aboard the vehicle as a compressed gas or cryogenic liquid; if it is generated at the point of sale by electrolysis, you can replace the inefficiency of trucking or piping the hydrogen with the efficient utility-line transportation of electricity, but you still have the other losses, and you add the fact that a smaller-scale hydrogen generator will be less efficient than a large-scale one. The jury is still out on whether it is more energy-efficient to use fossil fuels to make hydrogen than it is to burn them in a hybrid-electric vehicle, though on balance it looks likely that use of hydrogen will

cut down on ordinary combustion-engine pollutants like carbon monoxide, soot, and oxides of nitrogen. Stay tuned...