A Bridge to the Hydrogen Highway

By Greg Hanssen, EnergyCS
greg@energycs.com
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California has set forth on the ambitious goal of building a network of hydrogen fueling stations by the year 2010. This clean fuel 'Hydrogen Highway' is intended to solve the familiar 'chicken and egg' problem of vehicles and infrastructure. While the vision of a renewably fueled zero emission vehicle future remains clear, there are still many hurdles to be overcome before affordable Fuel Cell Vehicles (FCVs) are likely to reach the public. This paper proposes an enhancement to the FCV platform that would reduce vehicle cost, increase efficiency and alleviate the consumer anxiety over a sparse hydrogen infrastructure.

One of the rarely discussed issues is how the Hydrogen Highway could compete with a ubiquitous gasoline infrastructure. Prototype FCVs have only half the range of a traditional gasoline vehicle. How accepting of a medium-range vehicle will consumers be if the nearest refueling station is 10 miles out of their way? A solution: give the consumer access to refueling capability at home.

While home-based hydrogen generation devices may not be available in the near future, a hydrogen fuel cell based electric vehicle could easily gain additional driving range by enlarging the existing hybrid battery and adding a plug for home recharging. The electric energy gained from a home re-charge would complement the fuel cell and provide additional daily driving range beyond that of the hydrogen fuel cell itself. By expanding the existing fuel cell hybrid battery to a high-energy battery, a substantial portion of the daily driving could be done directly without the overhead of hydrogen production. The Hydrogen Highway would then allow such vehicles to go well beyond the traditional range of a normal battery electric vehicle. Renewably produced hydrogen would complement renewable electricity from the battery to allow unlimited range and quick refueling while also permitting inexpensive and convenient home refueling.

At the moment, fuel cell power comes at a high price. Current fuel cells approach $3000 per kilowatt although these costs are expected to drop closer to $1000/kW during the next phase of prototype vehicles. High energy, low weight advanced lithium batteries can now be purchased for as little as $200/kW. As long as fuel cell costs exceed that of batteries, there is a clear advantage to decreasing the fuel cell size and increasing the onboard hybrid battery. A battery-dominant hydrogen FCV would only need a fuel cell large enough to keep the battery charged for average driving as the battery would supply the additional peak power. At $1000/kW for the fuel cell, reducing an 80kW fuel cell to 20kW could save $60,000. Adding 50 miles of battery range would add less than $10,000 resulting in a net savings of $50,000 in the near to midterm.

Additional battery range would not only decrease infrastructure anxiety and vehicle cost, but could ultimately increase FCV efficiency. Advanced lithium batteries can return up to 80% of the electricity used to charge them. Using electricity to manufacture hydrogen and compress it, followed by a conversion back to electricity in a fuel cell may return as little as 20% of the original electricity. The battery portion of a plug-in FCV drive cycle would therefore deliver electricity to the motor up to four times more efficiently than through hydrogen. With renewable electricity at such a premium, great effort should be taken to use it as efficiently as possible.

Ultimately a plug on a hydrogen FCV could allow the vehicle to sell back hydrogen produced electricity for peak power needs or provide valuable voltage regulation services through the battery to further benefit the California electric grid. In the near term, while fuel cell costs exceed that of batteries, adding battery power and a plug will clearly increase the consumer and societal benefits of FCVs.

If the plug-in hydrogen FCV is the keystone in a bridge from gasoline to the hydrogen future, how do we complete this bridge? A plug-in gasoline hybrid could take the existing momentum of vehicles like the Toyota Prius and move us further in the direction of a renewably powered zero emission vehicle future by replacing more of the gasoline based driving cycle with renewably produced electricity. While adding a plug to a fuel cell vehicle reduces the vehicle cost, the same cannot yet be said for a gasoline hybrid. But this is likely to change in the very near future with fuel costs rising and battery costs dropping.

The EnergyCS/Valence Technologies plug-in hybrid Prius prototype demonstrates the viability of the gasoline plug-in hybrid concept. The ability to displace gasoline with electricity is accomplished by replacing the stock 1.3kWh NiMH hybrid battery with a 9kWh high-energy, lightweight Valence Saphion lithium-ion battery pack. The Toyota battery monitoring controller is also replaced with an EnergyCS lithium monitoring system. The EnergyCS control package consists of cell monitoring and balancing for the lithium batteries as well as pack voltage and current sensing, fan and charger control, user display and SD flash data recording.

The Saphion lithium battery pack can be externally charged with the on-board 120/240V charger in under 8 hours. While the expanded battery is sufficiently charged, the control system takes full advantage of built-in modes of the Toyota hybrid system to use electrical energy from the battery to displace gasoline. At lower speeds or power demands, the vehicle may run without burning any gasoline at all. When the expanded battery is depleted, the control system emulates normal Prius operation and the vehicle behaves like a normal Prius until the battery is recharged.

The amount of gasoline consumed over a normal daily driving cycle is dramatically reduced with the introduction of up to 9kWh of electricity from the grid. Preliminary driving tests over a variety of surface streets and freeways in Southern California have netted a gasoline efficiency of between 120mpg and 180mpg for the first 50 to 60 miles of the day. After 50-60 miles the average gasoline consumption drops back to 50mpg under normal Prius emulation mode.

The environmental as well as energy security implications of displacing gasoline with electricity could be tremendous. While plug-in hybrid gasoline vehicles like the EnergyCS/ Valence Prius could eventually help build a bridge to fuel cell vehicles, in the near term they could also dramatically reduce our reliance on imported fossil fuels.

As California strives to increase the amount of renewable electricity on the grid, vehicles that can be powered by this clean energy by way of batteries and hydrogen must be built to realize this zero emission vehicle future. The convenience, low cost and high efficiency of batteries combined with fast hydrogen refueling on the Hydrogen Highway make for the ultimate zero emission vehicle solution. In order to complete this bridge however, consumers must first be introduced to clean and inexpensive home refueling by way of plug-in hybrid gasoline vehicles.