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ACCELERATING THE HYDROGEN ECONOMY – ASEMBLON'S HYDRNOL™ CARRIER

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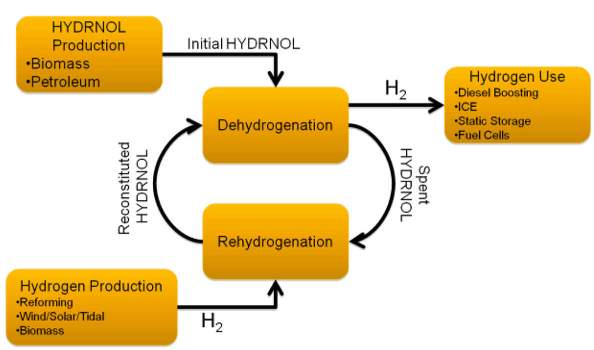
GENERAL BACKGROUND

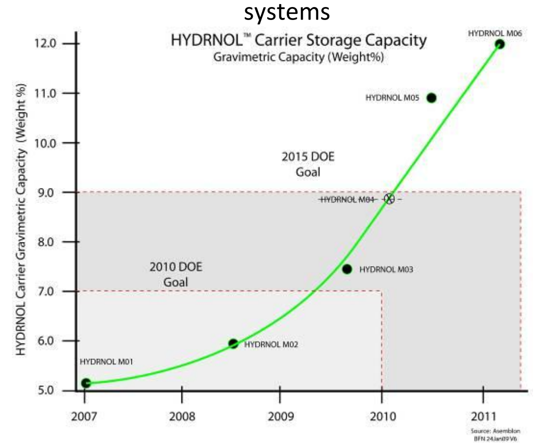
It is generally accepted that hydrogen is an ideal candidate to drive a society striving to establish sustainable fuel and power technologies. However, it is also well understood that the problem with hydrogen as a fuel, and a significant contributor to its total cost of deployment, is the ability to safely handle, store, distribute and deploy hydrogen. Asemblon's HYDRNOL focuses on solving this problem.

Figure 1. Asemblon HYDRNOL Carrier Concept



Asemblon, Inc. has patented a method for hydrogen storage and transportation using a family of organic liquid hydrogen carriers (HYDRNOL). HYDRNOL releases hydrogen, on demand, through a catalytic reaction. The spent HYDRNOL can then be re-hydrogenated back to the original HYDRNOL form i.e. recycled; this can occur at least 100 times, Figure 1. This approach delivers a liquid chemical system that offers significant advantages over liquid and compressed hydrogen. The prototype carrier (HYDRNOL-02) has the capacity to store 4.7% hydrogen by weight, with the initial commercial carrier (HYDRNOL-03) storing 7.4 % hydrogen by weight (US DOE 2010 target for vehicle use), Figure 2. Carriers with 11% and 12% hydrogen, by weight, are currently under research and scheduled for release in 2010 and 2011, respectively; 4+ years ahead of the DOE target of 9% hydrogen, by weight. HYDRNOL can be stored and transported as a liquid at ambient temperatures and pressures (-63 °C to 113 °C), which reduces safety concerns with regard to on-board or urban hydrogen storage. All these advantages allow relatively simple integration into the existing petroleum delivery and use infrastructure (pipelines, trucks and tankers), thus negating a need for a complete new infrastructure for hydrogen transport and storage. In static situations the carrier offers a central or distributed storage system that is as safe as gasoline or diesel for a vehicle network, hydrogen generators or fuel cells.

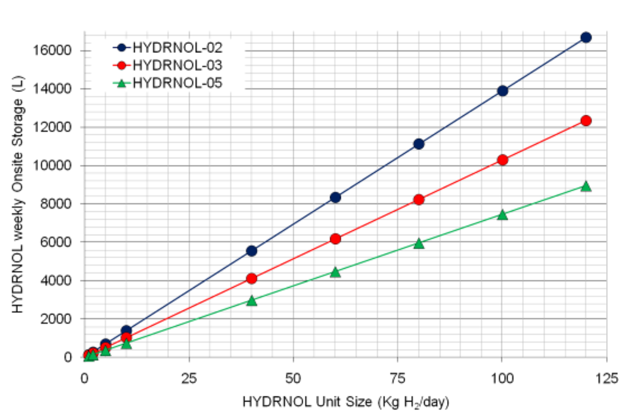
Figure 2. Expected rollout schedule for HYDRNOL systems



Near-term HYDRNOL is expected to enable the safe and economic transfer of hydrogen gas to the vehicle, long-term the HYDRNOL will be placed on board the vehicle for direct release of hydrogen to the engine on demand. To elaborate, in a stationary application, such as a hydrogen filling station an 8,000 L tank of HYDRNOL-05 containing the equivalent of 875 kg hydrogen can be placed on-site (the equivalent of a tanker truck delivery frequency of every 7 days based on 120 kg H_2/day usage), Figure 3. There are now two operational modes depending on the use requirements. If the vehicle has been modified to use an on-board reactor, a device akin to a catalytic converter, HYDRNOL can be pumped directly into the vehicle. However it is anticipated that early adoption will be to supply legacy compressed-hydrogen vehicles (fuel cell or H2ICE) by releasing and compressing the hydrogen from HYDRNOL stored at a filling station, with an on-site reactor system for direct hydrogen delivery to the vehicle. Along with vehicles, the HYDRNOL model can be used for static power systems such as generators and can be used with fuel cells to replace batteries.

The spent HYDRNOL is collected in a second tank. When the next batch of HYDRNOL is delivered to the station, the spent HYDRNOL is loaded onto the empty tanker and returned to a re-hydrogenation facility for recharging. The system is very simply scaled up - the larger the hydrogen demand, the larger the holding tank and number of reactors.

Figure 3. Onsite storage volumes for HYDRNOL



In all situations, the spent HYDRNOL can be re-hydrogenated on-site in a distributed or remote system, using localized solar or wind power to produce the hydrogen, or it can be returned to a central location for bulk re-hydrogenation using any technology that produces a high volume of hydrogen, such the steam reforming of methane. Asemblon is currently in teaming discussion with biomethane plant developers to deliver a fully ‘green’ enabled package to complement the use of hydrogen. There are logical assertions that research related to biomass and coal gasification technology, effectively an approach to create syngas, will ultimately lead to the cost of hydrogen to disconnect from that of traditional hydrocarbons. This endows hydrogen the potential to become the lowest cost sustainable fuel in all regions of the world.

As the HYDRNOL and dehydrogenated HYDRNOL are liquid at ambient temperature and pressure, with no material interaction issues, they handle exactly the same as gasoline or diesel. This means that the conventional infrastructure design of tanker trucks, riveted pipelines and non-specialized holding tanks significantly reduces the logistical costs associated with hydrogen delivery and storage for fuel use. Therefore, it follows that co-location of a bio-methane reformer and the HYDRNOL re-hydrogenation facility would allow the use of a renewable fuel, biomethane, presenting that fuel in a form that can be handled exactly the same as gasoline or diesel and can be distributed to urban based fuel stations following the petroleum fuel model.

The initial Asemblon approach delivers a liquid chemical system that, at the least:

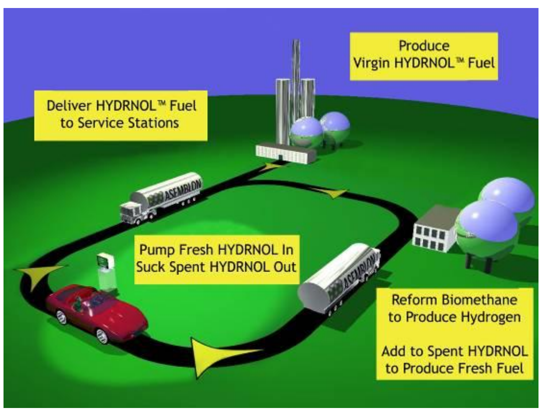
- Has the capacity to store at least 4.7% hydrogen by weight and up to 12% considering molecules that are known, currently identified or being developed
- Can be stored and transported at standard temperature and pressure, reducing the safety concerns with regard to on-board hydrogen storage
- Is a liquid over the range of -63 °C to 113 °C under ambient conditions, in both its hydrogenated form and its dehydrogenated form, allowing relatively simple integration into the existing infrastructure
- Is produced from a molecular precursor currently regarded as a low value by-product from both biomass and crude oil processing
- Releases hydrogen, as needed, using a catalyst, on board a vehicle or in a static location
- Is recyclable, where a method for adding hydrogen back to the dehydrogenated molecule has been developed but not optimized
- Offers significant advantages over the estimated cost and weight of the storage systems employing liquid hydrogen, compressed hydrogen and metal hydrides

APPLICATION OF THE HYDRNOL SYSTEM

HYDRNOL ADOPTION

Figure 4 demonstrates the HYDRNOL concept for a centralized production and re-hydrogenation system. Virgin HYDRNOL is produced from biomass or low value crude oil by-products at the generation facility. After the hydrogen has been released and used, the spent HYDRNOL is collected and transported to a second facility for reconstitution with renewably produced hydrogen. The reconstituted HYDRNOL is then delivered back into the use circuit.

Figure 4. Asemblon HYDRNOL Carrier Concept



As mentioned, the recyclable nature of HYDRNOL allows 'recharging' with hydrogen generated by any hydrogen production system such as wind, solar, tidal power, steam reforming of on-site fossil fuels, waste material reforming, excess power from nuclear sources or water electrolysis, Figure 5. Of especial benefit is that the recycling of the hydrogen carrier molecule significantly increases usefulness by reducing the economic cost, thus reducing operation expenditure (OpEx).

Asemblon is making considerable headway in to a long-range business plan to bring HYDRNOL to market worldwide. An initial project demonstration is being implemented in North Dakota, designed to demonstrate the advantage of storing electrolytically produced hydrogen where the power for the hydrogen production comes from wind turbines. Figure 6 shows a commercially available electrolyzer on site in North Dakota powered by electricity generated from wind turbines. Currently, the produced hydrogen gas is compressed to the white 5000 psi tanks, seen in Figure 6, for delivery to existing modified spark-ignition pick-up trucks and to a large farm tractor where the hydrogen augments combustion.. In

Figure 5. Hydrogen Production Pathways

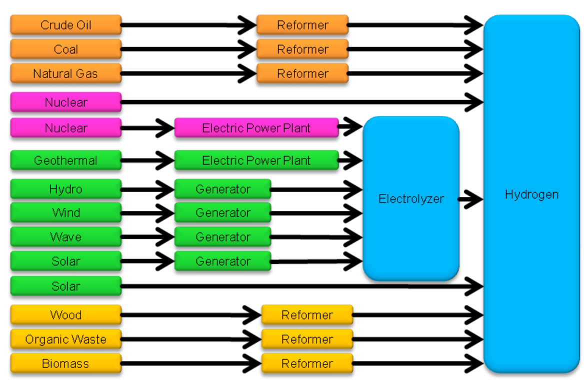


Figure 6. The electrolyzer system in North Dakota to be used for the first HYDRNOL demonstration.

2009, 400 gallons of HYDRNOL will replace these tanks.

A second demonstration site is currently in first stage development with the State of California. This would be at pilot-scale using fleet sites for distribution with the expectation of city-wide adoption on concept proof and acceptance. Asemblon is already working with several universities, industry leaders and in-house teams to achieve these goals.

The projected roll-out strategy of HYDRNOL molecules over the next 7 years consists of two molecules currently in scale-up., A third molecule is in development (7% hydrogen by weight) and an identified molecule currently in research which would deliver 12% hydrogen by weight after 2012.

IMPLEMENTATION OF HYDRNOL FOR ON-BOARD VEHICLE USE

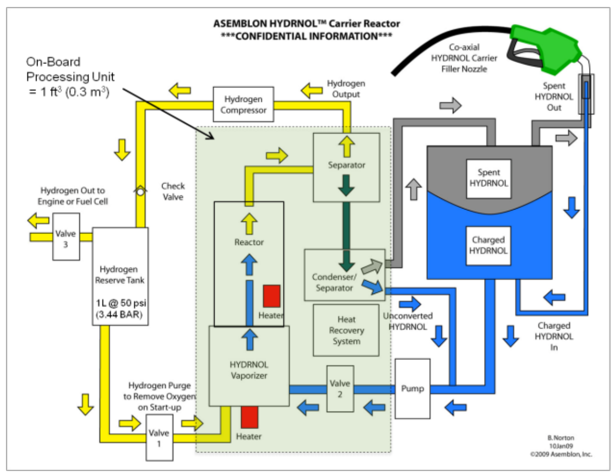
Hydrogen powered vehicles are being investigated. These investigations typically cover internal combustion engines (ICE), spark ignition (SI), compression ignition (CI) and fuel cells (FC). Normally the studies review retrofitting on existing legacy vehicles, but they also review the design of hydrogen specific engines.

While hydrogen can be introduced to the ICE via the air intake port the need for direct injection, for both SI and CI engines, is well recognized and the complex task of developing 'long life' hydrogen injectors is underway. Hydrogen is easily ignited, which is good, but pre-ignition will damage the engine and must be avoided. Hydrogen is fast burning (10 times faster than gasoline) perfect for high thermal efficiency. A 'tuned' hydrogen internal combustion engine will deliver 45% thermal efficiency, compared to about 25-28% for a gasoline engine.

As hydrogen combustion results in only water, undesirable emissions from a H2ICE would be expected to be almost zero. Ford Motor Company has recently reported that a H2ICE can be expected to demonstrate a 99.7% reduction in carbon dioxide (i.e. 300 H2ICE vehicles = 1 gasoline vehicle for CO_2 emissions), hydrocarbons and carbon monoxide to below 10% of Super Ultra Low Emission Vehicle (SULEV) standards and NOx certifiable to SULEV standards with modest after-treatment. Significant work has proven the potential to use hydrogen co-combustion and diesel displacement to supplement the tuned performance of a diesel engine to reduce SO_X and NO_X emissions. It is anticipated that HYDRNOL technology could enhance existing hydrogen dosing approaches in traditional truck and heavy equipment applications.

Fuel cell vehicles (FCV) have been seen as the ultimate replacement to the current gasoline ICE vehicle, however many barriers still hinder the adoption, such as performance and cost. Most FCV systems contain water, both as a byproduct and for humidifying the fuel cell, which can freeze at low temperatures. Therefore, fuel cells must reach a certain temperature to attain full performance. In addition, current fuel cells are prohibitively expensive for wide adoption, Honda estimate that their FCV, the Clarity, will cost nearly $100,000 in 2020.

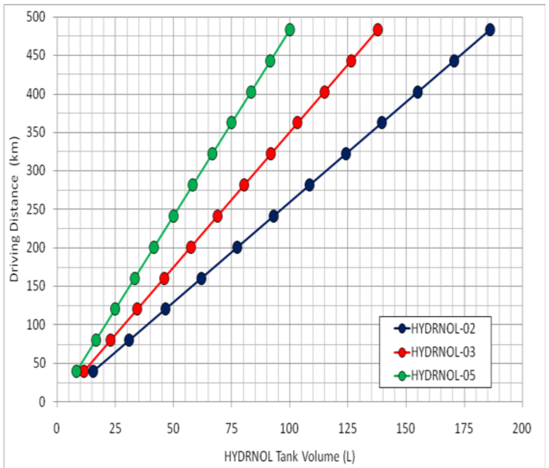
Figure 7. Schematic of a Potential HYDRNOL On-Board System



As HYDRNOL is independent of the power train, it can work with either SI/CI ICE or FC vehicles. HYDRNOL just presents hydrogen as a fuel at time of use. Figure 7 shows a potential schematic for the implementation of a HYDRNOL system on-board of a vehicle. As the Figure shows, a dual tube fuelling nozzle (already designed) loads HYDRNOL into a dual-chamber conformal bladder tank. A bladder tank is used as the volume of the tank will hold HYDRNOL and dehydrogenated HYDRNOL simultaneously, with no combined volume change in the liquids. The bladder also allows the incoming fresh fuel to aid in the discharge of the dehydrogenated fuel. The nozzle itself is designed to look exactly like the current gasoline fuelling station nozzle to make the fuelling/defueling system transparent to the vehicle operator. Once on the vehicle the HYDRNOL liquid is pumped into a vaporizer, passed through a reactor and the gaseous hydrogen separated from the dehydrogenated HYDRNOL.

The dehydrogenated HYDRNOL is returned to the conformal bladder tank. The released hydrogen may then be scrubbed, if a FC is being fed, to guarantee the required purity. If feeding a H2ICE, no scrubbing is required. A small 1 L (50 psi/3.44 BAR) buffer tank may be implemented if hydrogen demand peaks above the supply, although this is optional.

Figure 8. On-board Vehicle Storage Volumes

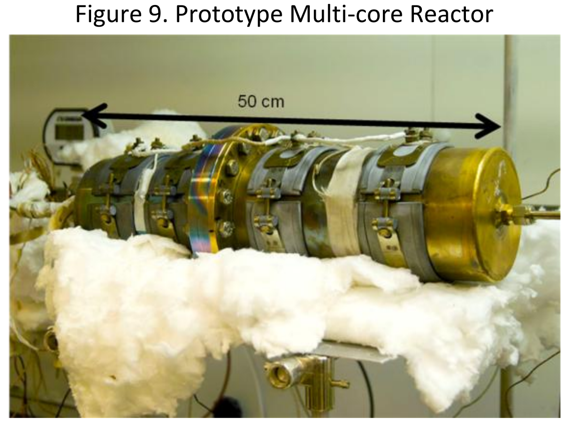


The on-board processing unit is around 1 ft^3 ($0.3\ m^3$) and potentially weighs less than 20 pounds when fully productized. The size of the tank is dictated by generation of molecule being used, Figure 8. The reactor, Figure 9, will employ a Waste Heat Recovery System (WHRS), similar to today's catalytic converters, which will be redundant in the HYDRNOL implementation, to minimize or eliminate the need for reactor heating except at start-up.

Much research has been published concerning on-board vehicular storage of hydrogen. The current focus appears to be with compressed or liquid hydrogen, or solid-state storage of hydrogen.

Other than HYDRNOL, current on-board hydrogen storage approaches involve compressed hydrogen gas tanks, liquid hydrogen tanks, metal hydrides, carbon-based materials/high-surface-area sorbents, and chemical hydrogen storage. In the area of on-board hydrogen storage, the state-of-the-art is considered to be 5,000- and 10,000-psi compressed tanks, and cryogenic liquid hydrogen tanks. None of these other approaches come close to the stated DOE targets for 2010, let alone 2015. Asemblon's HYDRNOL has much lower energy needs when compared to the energy required to compress or liquefy hydrogen. Both the hydrogenated carrier and dehydrogenated carrier are liquid between -63˚C and 113˚C, resulting in a material that can simply be pumped into and out of the vehicle, an action not possible with solid materials that store hydrogen. In fact the physical and chemical nature of the carrier allows easy integration into the existing fuel distribution networks, therefore overcoming one of the most widely recognized hurdles to the hydrogen economy, infrastructure change. In addition the proven recyclable nature of the chemistry minimizes waste or by-products and improves HYDRNOL's economic value.

Figure 9. Prototype Multi-core Reactor



Asemblon recognizes that weight is critical issue in automotive design which is a driving force for increased hydrogen gravimetric storage capacity. It is believed that the HYDRNOL approach already exceed the practical densities of other technological approaches such as metal hydrides. While it is recognized that HYDRNOL is not a panacea, it enables significant engineering design flexibility to assist in meeting challenges specific to the automotive industry

ADDITIONAL ENABLING TECHNOLOGY POTENTIAL

It is, conceptually, possible to design a hybrid system for current ICE engines that allows for HYDRNOL to be a storage mechanism where braking energy is converted to hydrogen, which is then used to recharge the used HYDRNOL. This ‘fresh’ HYDRNOL can then re-enter the system improving efficiencies.

HYDRNOL may enable a closed loop system when using a fuel cell. The fuel cell, when the vehicle is not in use, can be used to generate hydrogen with a feed of electricity and water. This hydrogen could then be used to feed an on-board hydrogenation system that created hydrogenated HYDRNOL for use the next time the vehicle is driven. In this situation, the HYDRNOL system could be considered a battery.

There are a number of non-automotive applications for the HYDRNOL strategy that include remote power and storage, power transmission, military and battery applications. It is clear that transportation applications are significant and have the potential to drive specific niche applications, with the ability to extend the reach of the automotive OEM market long-term.

HYDRNOL™ FUEL COST COMPARISON FOR VEHICLE USE

The use of hydrogen as a vehicle fuel has large benefits by reducing tailpipe emissions and allowing a transportation fuel from to be made from renewable sources such as biomethane, wind and solar.

Depending on the assumptions made in the model, there are also substantial benefits due to the improved mileage and power associated with hydrogen fuel.

To demonstrate these benefits, three different vehicles are compared:

1. A gasoline internal combustion car or light truck
2. A Ford F-150 light truck modified to run on pure hydrogen

3. A Fuel Cell vehicle, such as the Honda Clarity or Daimler SFCV

Vehicle 1 is assumed to get 27.5 miles per gallon of gasoline, the current Corporate Average Fuel Efficiency (CAFÉ) standard. Higher numbers are being demanded by environmental groups but are being fought by some in government and in court by the US automobile companies.

The amount of fuel is calculated that would be required for each vehicle to go 300 miles, the trip length specified by the US Department of Energy (DOE).

HYDRNOL was considered to be produced from biomass.

The central assumption is the cost to obtain hydrogen to recharge the HYDRNOL molecule. Prices vary over the range from $1.00 to $9.00 per kilogram depending on the source of hydrogen (nuclear is the least expensive and the wind-driven electrolysis of water is the most). For this model, we chose steam-reformed bio-methane at $1.47 per kilogram.

Since the HYDRNOL Carrier does not require either compression or cryogenic cooling, the hydrogen cost is not inflated by those post processing steps to prepare it for transport and storage. Instead, the hydrogen is incorporated directly onto the spent HYDRNOL molecule using an exothermic reaction (net energy out).

1. Running the model under these assumptions gives the following:

Fuel Efficiency

Gasoline ICE Engine	27	miles/gallon	Current CAFÉ Standard
Hydrogen ICE Engine	32.4	miles/kg	Ford F150
Hydrogen Fuel Cell	72	miles/kg	Daimler Smart Fuel Cell

Fuel Required to go 300 Miles

Gasoline ICE Engine Vehicle	11.11	gallons
Hydrogen ICE Engine Vehicle	9.26	kilograms H2
Hydrogen Fuel Cell Vehicle	4.17	kilograms H2

Cost ($) to go 300 Miles on Blended HYDRNOL (Current molecule-02)	**$**
Gasoline ICE Engine Vehicle ($2.00/gallon)	22.22

Hydrogen ICE Engine ($2.28/kilogram)	21.11
Hydrogen Fuel Cell ($2.28/kilogram)	9.51

HYDRNOL™ MARKET

The specific market for HYDRNOL is in licensing, along with all associated technology, in many energy segments. These include, but are not limited to fueling providers, alternative energy developers, automobile and truck manufacturers, the aerospace industry, infrastructure providers, power utilities and the parts and retrofit industry. The Company will seek specific partners who are willing to apply the technology to their specific application. In a co-development manner milestone driven, Asemblon will work with these companies to achieve full commercialization.

CONCLUSIONS

HYDRNOL is unique in the distribution and storage of hydrogen because as a liquid carrier, it can be implemented within the current fossil fuel infrastructure used for fossil fuels over the last 130 years. The technology has solved a potential Achilles heel of the hydrogen economy, and namely how to store, transport and release hydrogen without the need to undergo compression or cryogenic liquefying. Molecules are under scaling that exceed the DOE 2010 and 2015 hydrogen goals. HYDRNOL utilizing the current established fueling infrastructure is a major key to enabling hydrogen as a replacement for our fossil fuel system.

The technology can be used in any application where hydrogen is appropriate including for transportation ICE, FC and Co-Combustion applications. The implementation of the technology is able to keep pace with the technology developments anticipated in the transportation industry for the foreseeable future. The science is fully proven and only the scaling of the process is questioned. Key strategic relationships are vital to the success of the technology.