

Hydrogen Production and Supply Infrastructure for Transportation - Discussion Paper

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Hydrogen is a widely used industrial gas for a variety of applications such as the refining of crude oil, production of ammonia and methanol, the production of semiconductor chips, processing of edible oils, surface treatment of machined metal parts, etc. The annual worldwide production of hydrogen is about 50 million (metric) tonnes, the large majority (95%) of which is made and captively used within large refineries, and ammonia and methanol plants. There is also a smaller but rapidly growing merchant hydrogen industry, which makes and supplies about 2.5 million tonnes per year of the gas to third party customers. This market is well developed and rapidly growing, particularly in the United States, Canada, and Western Europe. To put this in some context for the present discussion about hydrogen as a transportation fuel, the 2.5 million tonnes/year is enough hydrogen to fuel a total of about 14 million hydrogen cars if they filled up once every 8 days with 4 kg of hydrogen each time.

Today hydrogen is most economically produced from natural gas (mostly methane) using a process called steam reforming. In this process, the hydrogen bound in the methane as well as hydrogen from steam is released. In addition hydrogen is also obtained as a by-product from petrochemical and chlorine-alkali plants. Another commonly used process is the electrolysis of water but this process is significantly higher in cost and is usually only used for very small-scale production and in remote locations where hydrogen delivery is not feasible.

The production and delivery of hydrogen for industrial uses is very mature technology. The hydrogen is often produced in large plants to take advantage of the economies of scale. The hydrogen from these plants is distributed as a gas via dedicated pipelines, via over-the-road high-pressure gas tube trailers, or as a super cold liquid via special cryogenic tankers by road and even by rail. These deliveries that number in the tens of thousands of trips and cover millions of road miles per year have been accomplished with an impeccable safety record over the last 4-5 decades. Today there are more than 1,000 miles of hydrogen pipelines serving large refineries and chemicals plants in several locations around the world. A massive build-up of hydrogen pipelines in the future to serve a hydrogen economy should have the same safety characteristics as the widespread natural pipeline networks that exists today. Hydrogen is no more dangerous than the gasoline that we are so accustomed to today. In many ways hydrogen has several mitigating factors that may make it more safe in an accident. For example as a rapidly diffusing gas any escaping hydrogen from a ruptured gas tank will vent straight up and leave the area of the accident very rapidly, while gasoline will pool on the ground and continue to burn with a very luminous flame. Thus passengers in a hydrogen car would likely suffer fewer burn-related injuries than in a gasoline car.

In the early days of hydrogen vehicle development (over the next 5-10 years) adaptation of the existing distribution infrastructure to the needs of the fuel application will be the most likely path forward. Today there exist many tens of hydrogen fuel stations in the United States, Europe, and Japan serving very small numbers of hydrogen demonstration vehicles. A large number of these stations are based on some form of delivered hydrogen to the site with the station having the

ability to store, compress, and dispense hydrogen at high pressure to the tanks onboard the vehicles. Hydrogen hauled in via high-pressure tube trailers¹ can work for up to 25 cars/day at a site. For larger fleets up to about 500 cars per day an installed fuel station with liquid hydrogen deliveries and storage on-site would work very well.

In addition to building fixed fuel stations for dedicated fleet projects which refuel at the same site, novel approaches like mobile fuelers which can be relocated at will and which can fuel vehicles at different sites as the need changes are also being introduced to serve the early demonstration needs. These mobile fuelers can be either refilled at a central plant and brought to the use point without the requirement for any utilities (external power or cooling water, etc.) or may have their own hydrogen generator such as a water electrolyzer to produce the hydrogen from water and electricity. Such units have begun to be introduced particularly in California where much of the fuel cell car activity is focused.

In locales where centrally produced hydrogen cannot be readily accessed the production of small quantities of hydrogen via reformation of other fuels such as natural gas, propane, butane etc. or via the electrolysis of water at the site of the fuel station will need to be adopted. Examples of this approach can be seen in Las Vegas, Tokyo, Iceland, and elsewhere. These small plants are still under development and are not commercially viable today but in some regions of the world there may be no other option to enable hydrogen fueling. As these units move down the development track and become reliable and achieve cost viability and as the demand for hydrogen fueling grows, it is foreseeable that such factory built reformer units could achieve low costs due to volume production. These new small-scale on-site reformers could handle fleet growth to fuel about 250-300 cars/day. These options therefore may have a life span that stretches from now until well into the future depending on their achieving the aforementioned objectives.

Water electrolysis is a very convenient way of starting to supply very limited numbers of vehicles. Systems small enough to serve even a single car may be deployed. The early stages of retail market development will be significantly enhanced by the option of home refueling using electrolysis, possibly with off-peak power rates. Generally the operating cost of electrolysis is high unless cheap electric power is available in off-peak hours.

In a future large and growing hydrogen economy (20+ years) it is likely that hydrogen will again usually be centrally produced at large facilities to achieve maximum economy of scale, reasonably near where it is needed (e.g. a large metropolitan area), and distributed to a large number of fuel stations via dedicated pipelines or as liquid hydrogen. The stations will have the ability to store and dispense the fuel much as they do today with petroleum fuels. It will still likely be produced from the same feedstocks as today — i.e., natural gas for some time to come. However, as renewable energy technologies reach a level of technology and cost maturity to compete with fossil sources, there will begin to be a shift away from current fossil-based hydrogen production to these alternatives.

A 1998 DOE study estimated the untaxed cost of hydrogen produced at various scales at the fuel station or delivered from large regional or remote reformers and dispensed at 5,000 psi to the vehicle. As expected there is a strong scale dependency of the hydrogen cost. The untaxed price of hydrogen to the vehicle ranges from almost \$7/kg (or GGE = gal gasoline equivalent) for a home-electrolytic unit capable of filling one car per day to about \$2.50/kg (or GGE) for very large-scale hydrogen plants capable of filling some 50,000 cars/day. However, it is important to recognize that significant capital investments are required to install the large-scale facilities to achieve the lower costs, which will only occur when there is clear indication of market demand. The untaxed hydrogen cost is higher than the average U.S. retail gasoline price, which is fully taxed (<\$2/gal) even at the very largest scales of production. Hydrogen would need to receive favorable tax incentives to permit market entry. The greater efficiency of fuel cell vehicles versus IC engine vehicles should also help to close the price gap between hydrogen and gasoline to help in market entry.

In addition to the potential need for favorable tax treatment as indicated above, policy efforts should also be focused on fostering harmonization of codes and standards for hydrogen fueling equipment and stations. This would be a great help in streamlining the permitting process for the build-out of the infrastructure. Currently no uniform codes and standards exist for the fuel applications of hydrogen and consequently local authorities largely decide requirements on a case-by-case basis, which often creates a barrier to timely construction of fuel stations. The federal government should play a coordinating role among the various code-making bodies in the United States, and lead the negotiation for harmonization with international bodies. Examples of codes and standards needed include on-board storage pressure (currently varies between 3,600 psi and 5,000 psi and development is underway to move up to 10,000 psi), and the type of nozzles used for filling the vehicle tank, as no uniform standard exists. Air Products' experience is that it takes a lot of time to convince local authorities of the safety of the hydrogen stations since we have no uniform standards to reference. Another area that requires significant attention is the education of the public about the use of hydrogen and its safety considerations to avoid the kind of undue fear and public opposition to fuel station installations that has been seen recently in London.

¹ A tube trailer is a set of high-pressure tubes mounted on wheels that transports hydrogen gas at a pressure of 2600 psi (a limit set by the DOT) over the road in regular commerce. They range in capacity from 60,000 SCF to 160,000 SCF.