Electrolysis: Technology and Infrastructure Options

Today, electrolysis systems supply 4% of the world's hydrogen. Although electrolysis can be competitive where low-cost electricity is available, market growth in the industrial sector has been limited due to strong competition from other, lower-cost, production methods, namely large centralized steam methane reformers. However, electrolysis is gaining ground in the alternative fuels market based on its flexibility and ability to deliver high-purity hydrogen using current electricity infrastructure. Electrolysis is becoming a technology of choice as more hydrogen fueling stations are being installed around the world to supply hydrogen for the growing number of demonstration vehicles. For example, five of the ten fueling stations for Europe's CUTE (Clean Urban Transportation for Europe) Program selected electrolysis systems to supply their bus fleets. Likewise there are many electrolysis systems already in operation at demonstration sites throughout the U.S., Canada and Japan.

Even in the early stages of market penetration of hydrogen-powered vehicles, nearly 300 hydrogen stations will be required along the U.S. interstate highway system. Ultimately, hydrogen stations must be located throughout cities and rural areas, similar to today's gasoline stations. The key challenge for electrolysis to provide a significant portion of this fuel remains the high price of electricity. For every kilogram of hydrogen produced, 60-90% of the cost is directly tied to the price of electricity. Based on current technology and average commercial and industrial electricity prices, today's largest electrolysis systems can produce hydrogen at a cost of $4-$6. Reducing system capital cost will help to improve hydrogen production economics, but electrolysis will only be cost-competitive with gasoline or other hydrogen production methods if low-cost electricity is available and the infrastructure to supply this electricity is available.

A priority of the U.S. Department of Energy's hydrogen research program is to develop electrolysis systems for fueling light duty vehicles. To approach economic competitiveness with gasoline, a 2010 goal of $2.85 has been established for electrolysis hydrogen production. Based on the efficiency improvement of a fuel cell vehicle, this begins to approach gasoline vehicles on a cents per mile basis. Two electrolysis topologies are proposed for integration into this fueling infrastructure. The first considers electrolyzers operating on-site at hydrogen fueling stations. These systems will range from 250 kW, for a transition-scale system servicing small fleets of vehicles, to 3 MW, for a station servicing 300 vehicles per day. In order to achieve the cost target of $2.85 per kg of hydrogen, electricity would need to be available to these stations at prices of 4.5 cents per kWh or less assuming full utilization of the station. As space and economics allow, and with a minimum of 1 day of storage, some trade-offs can be made in storage capacity to facilitate the purchase of off-peak electricity.

The second scenario offers a terminal hydrogen production facility at a substation level on the edge of a population center with potentially many such terminals around a large city. This facility could range in size from 10-100 MW, with multiple 2-3 MW electrolyzers operating in parallel. This facility could potentially be serviced by a high voltage line or could even be located on site at the power generation facility. From this terminal, compressed gas tanker trucks would deliver hydrogen to multiple fueling stations; many of these terminals could be located throughout the city. Because delivery will add an additional 70+ cents to the overall hydrogen cost (based on the DOE 2010 hydrogen delivery target), electricity prices of 3.5 cents per kWh or less will be required if we are to achieve the $2.85 target.

Electrolysis hydrogen production will likely be regional in nature and may be cost prohibitive in areas where electricity prices are high and infrastructure expansion is limited. Additionally, electricity generation emissions are a concern in the lifecycle analysis of hydrogen production from electrolysis. In order to compete on a carbon dioxide emissions basis with a 27.4 mpg gasoline vehicle, 31% carbon-free electricity would need to be added to the traditional US generation mix of 12% renewable, 54% coal, 18% nuclear, 15% NG, and 1% oil electricity. To compete with hydrogen produced by distributed natural gas reforming (at 75%LHV efficiency), 65% carbon free electricity would need to be added to the average U.S. generation mix. Ideally, hydrogen generation from electrolysis will produce near GHG free hydrogen by using electricity from carbon free sources in the future, but achieving these aggressive price and emissions goals will likely require unique market strategies in the near term and new carbon free and low-cost electricity technology in the longer term. Yet there are options that show promise for making these goals viable.

For example, the cost of wind-generated electricity continues to drop, with projected costs as low as 3 cents per kWh (for class 4 wind) within the next 8-10 years. However, even with tax credits, wind generation has, to date, been limited in its deployment. This is principally due the risks associated with its intermittent nature. Hydrogen presents a unique option for reducing this risk. Fuel and power generation can be integrated at the wind farm. Electrolyzer distributed at fueling stations can provide a controllable demand. Combined, this integrated hydrogen approach could result in wind providing a large quantity of the filling station demand for fuel. Concurrently, electricity production prices could be lowered, since the ability to shave the peaks and fill the valleys (by diverting some of the hydrogen produced to power generation) results in downsizing of new transmission lines, reduced congestion on existing transmission lines, and improved reliability of on-demand power generation.

In many regions of the country, generation capacity is becoming stranded due to the closure and/or export of industries. As an example, utilities in the southeastern U.S. have a large amount of installed nuclear (Duke >6,000MW and TVA >6,000MW). Due to economic reasons, many of the large textile mills operating in this region are shutting down leaving southeastern utilities with large amounts of generation capacity that could be available for hydrogen fuel production. Similarly, throughout the country, hydrogen production via electrolysis can be integrated with storage to take advantage of off-peak electricity prices. Advanced grid control systems that allow automated electrical usage based on price signals can be installed to maintain low operating costs and reduce electrical congestion. Self-generators could potentially profit through hydrogen fuel production, even in cases where costs for transmission rights are added. Overall, these strategies will allow us to use the electric system more efficiently.

In summary, market strategies for deployment of electrolysis for fuel production must be assessed at the local and regional level. There are numerous opportunities to diversify electricity generation and markets. Ideally, electrolysis will be able to provide hydrogen fuel for at least 20% of our light duty fleet; we will be able to do this at prices competitive with traditional fuels and other hydrogen production pathways, using domestically available resources, and without adverse impacts to the environment. However, to be successful, the utility sector must play a vital role in identifying these opportunities and must look at transportation fuel as a high priority business opportunity for the future.