

CAVENDISH HYDROGEN FUELING STATION COSTS

Prepared for the California Air Resources Board

By

Cavendish Energy, LLC, August 2016

Cavendish hydrogen is a viable third option for cost-competitive hydrogen fueling station applications. The on-site hydrogen prices at fueling stations in Southern California (which are partially or substantially subsidized) are \$20+/gallon gasoline gallon equivalent (GGE). For example, the cost is about \$30/GGE at Harbor City Mebtahi Chevron, Harbor City, CA. However:

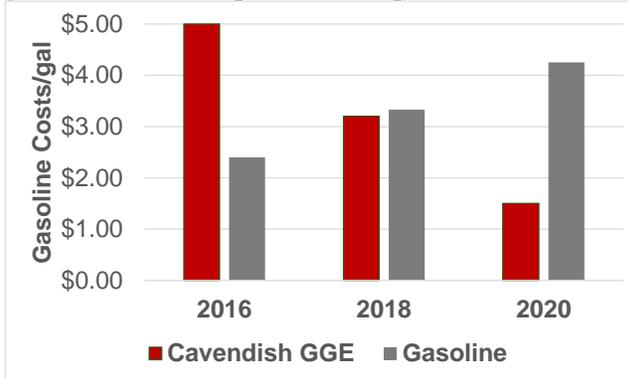
- Cavendish Energy™ currently produces hydrogen *on-site* at less than half the current going rate of either steam methane reforming (SMR) or electrolysis.
- By 2018, Cavendish forecasts that it can produce, via the Cavendish Process™, hydrogen *on-site* at less than one-third the current going rate and competitive with the U.S. Energy Information Administration (EIA) forecast average U.S. cost of regular gasoline.¹
- Including the byproduct value, aluminum hydroxide -- Al₂(OH)₃, Cavendish can produce hydrogen *on-site* at less than 25% the current going rate for H₂ and significantly less than the average U.S. cost of regular gasoline.
- By 2020, Cavendish forecasts that it can produce hydrogen *on-site*, including the byproduct value at less than one-half the EIA forecast average U.S. cost of regular gasoline.

As illustrated in Figure 1:

- The current, 2016 cost of Cavendish hydrogen in GGE is about twice the current U.S. average cost of a regular gallon of gasoline.
- In 2018, Cavendish forecasts that the GGE cost of hydrogen produced via the Cavendish Process™ will be slightly less than the EIA forecast U.S. average cost of a regular gallon of gasoline.
- In 2020, Cavendish forecasts that the GGE cost of hydrogen produced via the Cavendish Process™ will be less than half the EIA forecast U.S. average cost of a regular gallon of gasoline.

¹U.S. Energy Information, *Annual Energy Outlook 2016*, 2016.

Figure 1
Current and Cavendish Forecasts of Hydrogen GGE Costs
Compared to Average U.S. Regular Gasoline Prices



Note: A fuel cell vehicle is 2X as efficient as a gasoline vehicle

Source: U.S. Energy Information Administration and Cavendish Energy, LLC.

A Cavendish hydrogen fueling station will have significant advantages over conventional hydrogen stations; for example:

- A Cavendish fueling station can be constructed for one-third to one-half the costs of current, conventional hydrogen fueling stations.
- The footprint of a Cavendish station will be relatively small compared to current alternatives.
- The Cavendish Process™ can produce hydrogen reliably at the volumes required, in either continuous or batch process.
- Cavendish fueling stations produce the hydrogen on location and can be established at a wide variety of locations, including current gas stations, car dealerships, universities, fleet locations, industrial sites, etc., including indoor facilities.
- The Cavendish system is modular and produces hydrogen on-site, and is thus not overly dependent on a domestic supply chain for equipment parts.
- Cavendish fueling stations will be cost-competitive for fleets and for general FCEVs.

Several additional points should be noted:

1. The price of gasoline in California is typically about 20% higher than the U.S. average, and Cavendish hydrogen is thus even more competitive in this state.
2. The price of premium gasoline is typically about 10-15% higher than regular gasoline.
3. The Cavendish Process™ byproducts offer potential in the production of high-value specialty alumina for use in products, including ceramics, refractories, abrasives, glass, and flame retardants.

4. Further refinement of the Cavendish Process allows the recycling and reuse of water, which will further reduce the net cost of the hydrogen produced.
5. The Cavendish Process facilitates the production of desalinated water, which is a potentially high-value byproduct.
6. The Cavendish Process produces heat with a BTU value greater than that of the hydrogen produced, and this heat can have substantial value either used directly (heating and fishing cabins, etc.) or via CHP.
7. Cavendish can utilize recycled aluminum as the input, and Cavendish hydrogen thus qualifies for California's low carbon fuel credits and contributes to the state's mandated renewable energy goals.
8. The Cavendish Process™ has been tested and verified by the Gas Technology Institute – one of the premier R&D labs in the U.S.

All of these factors increase the value of the Cavendish Process™, including both hydrogen production and process byproducts. Thus, the Cavendish values estimated here must be viewed as conservative. Further:

- A major advantage of the Cavendish Process™ is that aluminum is the energy storage mechanism, and it is nonhazardous and easily transportable and can be stored indefinitely.
- The Cavendish Process™ delivers the hydrogen, on-site on demand, where and when required and thus incurs no transportation or storage.
- Cavendish has batch or continuous operation capabilities.