

*Knowledge Paper*

## *Hydrogen Power*

# *Air Products marshals its strengths for the hydrogen economy*

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*This paper is published to encourage the sharing and transfer of knowledge.*



*The daily headlines tell the energy story: growing demand, shrinking supplies, soaring costs, and worries about emissions, security, politics, and trade. Is it any wonder the world looks to alternative sources of energy to solve a nettlesome knot of problems?*

*Hydrogen holds tremendous promise.*

*It is renewable, abundant, and efficient. And unlike other alternatives, it produces zero emissions. Many believe this versatile molecule will become the primary fuel and energy carrier of the future. Count us at Air Products among the faithful.*

*Air Products is the world's largest supplier of merchant hydrogen. We have been for decades. Our expertise in producing and distributing hydrogen safely and economically for industrial uses is well established.*

*Now we are applying that skill and experience in new ways. We are at the fore of many fronts in the development of hydrogen energy technology, contributing our expertise to a number of hydrogen energy projects across the United States and around the world. Some have a long-term view.*

*Hydrogen is available today in various forms and applications. For example, hydrogen is being used as fuel in internal combustion engines (ICEs) and in compressed natural gas (CNG) blends. However, full adoption of the hydrogen economy will not occur for years. In the interim, we are doing two things. We are taking a leadership position in the development of the infrastructure necessary to support safe, affordable hydrogen distribution. And we are exploring innovative, environmentally friendly means of hydrogen production and distribution.*

*We will review here several of these efforts. But first, let's take a quick look at some of the issues surrounding the use of hydrogen as a primary source of fuel.*



## Hydrogen in the limelight

Hydrogen made national headlines in 2003. In his State of the Union address, U.S. President George W. Bush said, “With a new national commitment, our scientists and engineers will overcome obstacles to taking these cars from the laboratory to showroom so that the first car driven by a child born today could be powered by hydrogen, and pollution free.”

But interest in hydrogen as one solution to future energy needs began long before that. Air Products started exploring hydrogen as a fuel as early as 1989. We’ve increased those efforts as automakers began looking at hydrogen to make vehicles more efficient and less polluting. One area of interest that we’ve explored is the complex set of issues surrounding the dispensing of hydrogen fuel at the consumer level. Not surprisingly, safety and cost are paramount issues that must be resolved. Let’s look at each one.



A report on the hydrogen economy by the National Academy of Engineering (NAE) noted that experts differ markedly in their views of the safety of hydrogen for a consumer transportation system. Some oil companies prefer separate stations for hydrogen. Others want to dispense gasoline, diesel, and hydrogen, all at the same facility. Integrating current fueling methods with development technologies raises liability issues. The industry has insufficient experience with codes and standards for this application. So the potential for litigation could stifle continued development.

The next consideration is cost. As with most emerging technologies, cost at this stage is a major barrier to commercialization. Currently, the cost to develop a hydrogen fuel cell vehicle is roughly on par with the cost to build the dispensing station. The NAE report notes that it will take at least a decade for fuel cell systems to develop a competitive cost picture. Fuel cell vehicles are not projected to enter the light-duty (car and truck) consumer market in significant numbers until 2010–2015 or later.

Hydrogen distribution costs for the low-volume user over the next several years will also be relatively high, especially for a product that will, in a hydrogen economy, become a commodity. The current distribution system for hydrogen is set up for industrial customers, not consumers. Most hydrogen is generated and consumed on-site at refineries and chemical manufacturers. Air Products does operate multiple hydrogen pipeline systems. But these are for industrial users, a very small number of large-volume users compared to the thousands of stations that would be needed to supply millions of low-volume consumers.

Although today's costs are high for the low-volume consumer market, hydrogen is currently attracting attention in the mass transit industry, which faces stricter emission-control mandates. Transit authorities and energy departments need clean, efficient alternative fuels. A blend of hydrogen and compressed natural gas (HCNG) can offer significant benefits in terms of emission reduction. Applications like this can serve as a springboard to the consumer market.

## Matching production methods to goals

Hydrogen fueling represents a tremendous future opportunity. Air Products and others are working on it. But there are other, more immediate needs. For one, to maximize the benefits of hydrogen energy, it is necessary to develop independent and greener methods of production.

Current processes still depend heavily on fossil fuels. Currently, about 80 percent of merchant hydrogen is generated through steam methane reformers (SMR)—a hydrocarbon-based process that requires natural gas and that generates carbon dioxide as a by-product. While this mode of production is not based on renewables, various well-to-wheels analyses have shown that SMR-based hydrogen fuel will reduce greenhouse gas emissions overall.

Electrolysis is another existing method for generating hydrogen. It separates water into its elements, hydrogen and oxygen. Unlike SMR, electrolysis has potential both to reduce CO<sub>2</sub> emissions and to enhance energy security. But it requires significant amounts of electricity. This generally turns out to be far more expensive than the merchant-produced hydrogen.

The challenge, then, is what to do in the short term to promote energy independence, energy efficiency, and reduced emissions? Several technologies have the potential to meet these goals and to support the development of an economy based on renewable hydrogen energy. Here are some of them. The ultimate answer to the energy problem may lie in getting hydrogen from several of these sources.

**Biomass:** Agricultural products and food waste could provide an inexpensive, readily available and renewable source of hydrogen. Any organism—plant or animal—can be used to create hydrogen and/or methane. According to the U.S. Department of Energy and Agriculture, one billion dry tons of biomass could supply approximately 30 percent of the energy needs of the United States. And biomass is readily available. But more efficient methods are needed to make this a viable source.

There is progress in this area. For example, Air Products is working with the University of California at Davis on a process that utilizes anaerobic bacteria to generate hydrogen, rather than methane, from biomass. In Brazil, sugar cane is being converted into compressed natural gas through cellulosic digestion. Plants near agricultural sources could provide local hydrogen to lower distribution costs.

**Waste-to-Hydrogen:** Hydrogen can be generated through technologies that turn municipal, medical, and industrial wastes into a synthetic gas (syngas) that contains hydrogen. The syngas can be used to produce power, or the hydrogen can be recovered and purified. In addition to generating a usable source of energy, this process provides an alternative to landfilling hazardous wastes.



**Coal Gasification:** Economies of scale, operating logistics, and capital requirements make coal-to-hydrogen methods most suitable for large, centralized plants. As a result, the path to the lowest-cost coal-to-hydrogen technology for the long term will come from highly integrated gasification coproduction (IGCC) processes that generate hydrogen and electricity. Coal represents a long-term opportunity to supply hydrogen in significant centralized quantities, similar to the manner in which nuclear power is supplied today.

**Nuclear Generation:** New nuclear technology that can be linked to hydrogen production can provide a platform for supply of the hydrogen economy. An integrated approach to the design of nuclear power generation, coupled with waste heat to produce hydrogen, can offer a low-cost source of hydrogen. Generation from central plants would likely be integrated with an industrial gas supplier's current infrastructure, storage, and distribution systems.



## Taking steps toward the future

As a clean, efficient fuel that can be generated from renewable resources, hydrogen offers tremendous potential.

Questions remain and issues must be resolved before the business case is clear for any specific application. But we at Air Products are optimistic about hydrogen energy, and we bring significant generation, separation, and distribution resources and experience to the table.

We understand the wide range of issues involved in the transition to hydrogen energy—technical, operational, social, and economic. With decades of experience in hydrogen applications and an unsurpassed safety record, we offer a wide range of strengths in this pursuit. They include safety, engineering, business analysis, and project management services to support customers in this area. We believe that the hydrogen economy is already in development and that it will be based on market forces for the supply of lowest-cost energy. The full transition may take decades.

We envision a multiphased process. Here are the major components of that process.



**1) Leverage current infrastructure:** Air Products is already leveraging its existing infrastructure to provide hydrogen to oil and automobile companies for emerging applications. The production cost of hydrogen today, at a major generation facility, is equivalent to the cost of gasoline. The distribution costs, however, are significantly higher than those for petroleum-based fuels. To reduce these costs, we are developing new, more cost-effective means of delivering hydrogen to the consumer with technologies that “piggyback” on the merchant hydrogen business.

**2) Stranded gas cleanup:** We can apply our core skills in gas processing and separation to develop clean alternatives to today’s methods of hydrogen generation. One example is capturing and separating “stranded” gases or generating hydrogen from renewable sources. Another is obtaining hydrogen from chemical processes that have effluent streams (“off gases”) with high hydrogen content. This includes chlor-alkali, ethylene, and styrene production. Many of the technologies widely used today to separate gases from the industrial waste gas stream could be applied to coal beds or shale beds to obtain usable methane. As a leader in separations technology, Air Products can deploy solutions for recovery and conversion of these streams.

**3) Multiproduct assets:** We also are applying our process and engineering expertise to approaches that incorporate multiple products—for example, energy stations that cogenerate hydrogen and electricity. For the U.S. Department of Energy, Air Products found that high temperature fuel cells (HTFCs) designed and operated to produce both hydrogen and electricity do offer a potentially attractive means of rolling out the hydrogen fueling infrastructure. Coproduction from HTFCs is a potentially economical and sustainable means of producing and delivering hydrogen for fueling applications.

**4) Renewable generation:** Means of renewable energy generation that have less-than-favorable energy economics today will become more competitive in the future. It is fully expected that biomass, waste recovery, conversion of sugars and alcohols and nuclear power will become major sources of hydrogen generation in the future. Additionally, wind, solar, geothermal and hydropower through electrolysis have the potential to provide hydrogen and power in select regions.

What’s more, new technology for hydrogen generation will continue to be explored. We can imagine a future in which every household may have the capability to generate some quantity of hydrogen to supply its needs. By definition, the long-term sustainable answer to our need for power has to involve renewable sources.

## Summary

In the end, the hydrogen economy will be driven primarily by market forces. We are committing resources to energy industry consortia, academic initiatives, and steering committees to learn what automobile manufacturers, oil and gas companies, and their customers want. We are working with multiparty teams to move hydrogen energy applications forward. We are firm believers that a future hydrogen economy is a realistic outcome with the continued depletion of fossil fuels. The question is not *if* the hydrogen economy will happen, but *when*.



## For More Information

If you would like additional information, write or call Air Products at the location below, or visit our website.

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