Hydrogen Utilization in the Electricity Sector: Opportunities, Issues, and Challenges

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About the Strategic Energy Institute

Few sectors affect the prosperity of every sphere of economic and social life or exert as much direct influence on general technological progress than energy. Concerns surrounding climate change, cost, equity, and security, have brought the development of a clean and diverse energy portfolio to the forefront of the national conversation.

Founded in 2004, the Strategic Energy Institute serves as system integrator for the more than 1000 campus researchers working across the entire energy value chain. We are deeply engaged in building community, developing resources, and projecting thought leadership, all with the aim of marshalling the full resources of Georgia Tech around tackling the tough energy and environmental problems society faces.

As the nation's largest technologically focused university, Georgia Tech is playing an integral role in developing the technologies that are enabling more equitable, lower cost, and cleaner generation, storage, distribution, and utilization of energy. Researchers at Georgia Tech are not just helping to create cleaner, more efficient fuel options or mitigate the environmental impact of conventional energy supplies, they are creating better performing, more economically viable energy options.

About the Electric Power Research Institute

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery, and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety, and the environment. EPRI also provides technology, policy, and economic analyses to drive long-range research and development planning, and supports research in emerging technologies.

EPRI members represent 90% of the electricity generated and delivered in the United States with international participation extending to nearly 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; Dallas, Texas; Lenox, Mass.; and Washington, D.C.

Introduction

When the sun is shining and the wind is blowing, solar and wind energy are the lowest cost sources of electric power in the country. This energy can be used to directly power electrical devices, such as lighting for buildings or charging electric vehicles. It can also be stored in batteries for short term storage or can be used to make hydrogen, which can be stored or put in a pipeline for later use, including users that are a long distance away. On the other hand, natural gas fired gas turbines are both the lowest cost non-intermittent power source, and the largest source of electric power in the US, at around 40%. Can they continue to evolve and be repurposed to utilize stored hydrogen for electric power?

To address this question, it is helpful to back up and consider where hydrogen might fit within the energy system as it stands today. The US energy system can be divided into three major subsystems: (A) *energy sources* (natural gas, oil, solar, etc.), (B) *carriers and infrastructures for moving energy sources around*, and (C) *energy consumers*. This whitepaper considers issues associated with hydrogen as an energy carrier, particularly its role as a substitute for natural gas.

Currently, the energy system is dominated by two largely independent, multitrillion-dollar carrier systems - electricity and fossil fuels. In the US today, roughly 40% of energy is carried via electricity and 60% via fuels. Fuels are chemical-based energy carriers with high energy densities that are moved via pipelines, trucks, rail, or ships and today are almost completely based on fossil fuels, such as natural gas or crude oil. These systems leverage millions of miles of pipelines, a significant petrochemical manufacturing base, and serve a global user network, including vehicles, industrial processes, and building heating. For further perspective, consider that natural gas is the largest energy source for electricity in the US, and a very close second to petroleum for all energy sources in the country. While many questions remain about the relative roles of electricity and chemical energy carriers in a decarbonized economy, two things seem clear: (1) use of fossil fuels as energy sources and carriers will decrease, although probably not to zero, and (2) use of “manufactured” chemical energy carriers, (like hydrogen) that are produced using renewable power, will grow. In considering the potential for manufactured chemical energy carriers (such as using hydrogen to replace natural gas), it is important to elaborate on the distinction between energy sources and carriers. Natural gas is both a source and a carrier of energy. Hydrogen, in contrast, requires a source of energy (for example renewable power, such as wind) to make the hydrogen which then can be utilized as an energy carrier.

There are three key issues to consider when using hydrogen as an energy carrier: (1) generation of hydrogen, (2) logistics, handling, and movement of hydrogen, such as via pipelines, and (3) utilization of hydrogen by “energy conversion devices” such as fuel cells, gas turbines, or boilers to generate electricity or heat.

This whitepaper addresses issue (3) – the opportunities and challenges associated with utilizing hydrogen in energy conversion devices, particularly as a replacement for natural gas in existing systems. This approach has several key advantages. For example, hydrogen can be stored and used during times of peak demand. This has the benefits of re-purposing existing technology (e.g., gas-fired plants and natural gas infrastructure) for energy storage and conversion with no carbon emissions. This raises the following questions:

1. Is hydrogen viable as a fuel in existing systems, or are retrofitted devices or new systems required?
2. If so, what are the constraints or issues that must be understood by policymakers, generators, and the public?

Can Hydrogen be Cleanly Used in Energy Conversion Devices?

The answer to this question is emphatically yes. There is no fundamental reason why hydrogen cannot be combusted in gas turbines, heaters, boilers, reciprocating engines, or any other combustion system. It can be burned as pure hydrogen, or blended with any other fuel such as natural gas. In fact, today hydrogen is used as a dominant fuel source for a number of power generating plants, such as the Fusina hydrogen power station in Italy (nearly 100% hydrogen electric power plant), the Daesan Industrial Complex in Seosan, South Korea (95% hydrogen petrochemical plant), Wuhan Iron & Steel Group Corp (60% hydrogen steel mill), and several planned facilities converting to 100% hydrogen such as Vattenfall's Nuon Magnum power plant in Eemshaven, Netherlands, and the Intermountain Generating Station in Delta, Utah. It has been flown in several specially designed aircraft and aircraft manufacturers have pledged future hydrogen aircraft such as the Airbus ZEROe. Furthermore, a number of systems have been developed that are both clean burning (explained further below) and capable of burning up to 100 % H_2 for future installations.

What are Constraints with Using Hydrogen in Existing Systems?

While hydrogen combustion offers a promising energy storage and conversion pathway, it is not a "drop-in" fuel for much of today's natural gas fired devices. In other words, alterations are needed in the fuel handling systems, valves and piping, and combustor hardware. These alterations are needed to address the interdependent issues of pollutant emissions, operability, and cost, as explained next.

We address pollutant emissions first. In addition to concerns around CO_2 emissions associated with climate change, combustion can generate other pollutants, even with zero-CO_2 fuels like hydrogen or ammonia. Pollutants most commonly associated with fossil fuel combustion are particulates (e.g., soot), carbon monoxide, and NOx. Hydrogen combustion emits no particulate or carbon monoxide emissions, since it contains no carbon atoms - another major benefit of it as a fuel. However, hydrogen combustion can generate nitrogen oxides (NOx) emissions. In essence, NOx is generated when air is heated to high temperatures and the constituents of air start to react with each other. NOx is a regulated pollutant because of its potential to cause adverse respiratory health effects, smog, and acid rain.

So called "dry, low NOx" (DLN) combustors are inherently low NOx systems because they avoid the high temperature operating ranges that produce NOx. These technologies dominate new electric power plant installations and the predominant technology in the current power generating fleet. However, there are tradeoffs between operational flexibility in NOx emissions without customized hardware developed for high H_2 levels. Without dedicated hardware, operational challenges limit the maximum amount of hydrogen that can be used.

Next, it's important to understand the connection between efficiency of the engine and its NOx emissions. An approximate rule of thumb is that higher efficiency machines run at higher temperatures and, therefore, emit higher NOx emissions. For reference, current EPA regulations on NOx for gas turbines is 30 ppm, while in certain areas with air quality problems, they can be as low as 3 ppm. The highest efficiency devices, combined cycle gas turbines, are now designed to operate with NOx emissions between 1-25 ppm. Since they are designed to operate at a fixed temperature, hydrogen addition need not adversely impact NOx emissions for DLN combustors. Given this point, it is important to correct some common misperceptions. Since NOx emissions increase exponentially with temperature, and because hydrogen can burn hotter, it's sometimes said that hydrogen combustion will produce more NOx. However, this point needs to be contextualized relative to old technologies or modern DLN systems. It is true for older "diffusion flame" technologies, which are inherently high NOx devices, and rarely used in the US or Europe. It is NOT necessarily true for dry low NOx systems. For big, high efficiency engines, H2 addition effects are very small. However, for smaller engines, such as microturbines that might emit 1-3 ppm, the effect could be noticeable – for example, a 1 ppm emission level could become 2 ppm – in other words a small absolute increase, but a large relative one. However, the key point here is that DLN hydrogen powered systems can be designed for ultra-low NOx emissions.

To summarize, this whitepaper has shown first that hydrogen is an acceptable, very clean fuel. Second, H_2 can be used at limited levels in existing fielded systems, and some low NOx gas turbines exist in the field today that can operate with H_2 levels of up to 50%, co-fired with natural gas. Current technology development is focused on low NOx, fuel flexible systems, that can be readily operated with a range of fuel compositions, ranging from pure H_2, to blends with other fuels.

Note: A more detailed presentation of this material can be found in Power Engineering Magazine with the same authors and title, or online at:

https://www.power-eng.com/gas/hydrogen-substitution-for-natural-gas-in-turbines-opportunities-issues-and-challenges/