NCC Part I
Coal-to-Hydrogen
DBE

Hydrogen

Before anyone can understand the complexities of the so-called hydrogen economy, it's important to understand why hydrogen is sought after at all. First of all, hydrogen (H2) is a colorless, odorless, tasteless and non-toxic gas at atmospheric temperatures and pressures. But it's also one more thing: absolutely packed with energy. In fact, hydrogen has the highest combustion energy release per unit of weight of any commonly occurring material. That means you can get more heat from hydrogen than almost anything else. And its only byproduct is water. One more advantage. It's everywhere.

Hydrogen Uses and its production

Right now, the United States uses more than 9 million tons of hydrogen for a variety of uses, mostly commercial such as the production of fertilizer. The space program also uses it as a fuel.

At the moment, over 95% of the hydrogen produced in the U.S. comes from steam reforming natural gas. That means the hydrocarbon in natural gas is split into hydrogen and carbon. That's fine, but it doesn't solve the greenhouse gas problem because carbon is going into the atmosphere and it doesn't solve the dependence problem because you're using mostly foreign natural gas. In addition, compared to the amount needed to replace the fuels to power industry and transportation, an almost insignificant amount is being produced (figure).

The Hydrogen Economy

People have entertained a hydrogen economy because it offers at least four solutions to the current oil/natural gas-based economy.

- Most oil and gas come from beyond our borders, hydrogen is everywhere. By using more hydrogen, our dependence on foreign sources declines.
- Because so many people want oil and gas worldwide, demand is greater than the supply and the cost is going up dramatically.
- Fossil fuels produce air pollution, hydrogen doesn't.
- Carbon dioxide could be changing the climate. When oil spills, it affects the environment. Hydrogen has none of these effects.

So if hydrogen can be produced from domestic energy sources in a way that is affordable and environmentally sound and if we could get to the stage where hydrogen would replace, say, gasoline in cars that would run as well or better than today's automobiles, wouldn't that be a good thing?

Yes. But there are a lot of hurdles to cross first such as the cost and means of wide scale production, distribution, storage, codes and standards, infrastructure. When fossil fuels began to be used widely at the beginning of the 20th century, all these problems had to be addressed as well. It's only because they are all in place that it continues to make the use of oil and natural gas seem easier, and it is. But questions of security, cost and availability are quickly creating the opportunity for hydrogen.

The first question that needs to be faced is whether hydrogen can be produced on a large scale at an affordable cost in an environmentally benign way. The second question is whether hydrogen can be distributed and stored safely and efficiently. The third question is whether hydrogen can make the transition into use for transportation fuels on a widespread basis. It is to these questions we now turn.

Hydrogen production and coal

The U.S. government has identified the use of coal as the most promising fuel to produce hydrogen on a large scale. The reasons for this are clear: coal is abundant (the U.S. has more coal than any other country in the world), coal is much less expensive than oil or natural gas and the technology exists to use coal in producing electricity and hydrogen at the same time, thus reducing the cost of producing the hydrogen at all.

There are two main problems with this coal-to-hydrogen process. First, what can be done with the carbon that results when hydrogen is split off from the carbon without releasing it into the atmosphere?

Second, no one has ever produced hydrogen from coal on a large scale before.

What is clearly needed is a pilot project to answer both these questions and it's already been called for by the President. The U.S. Department of Energy is going to partner with members of the energy industry to build, operate and evaluate just such an operation called FutureGen.

A main objective of this project is not only to produce hydrogen and electricity with zero emissions but to see whether the carbon can be safely, efficiently, economically and permanently sequestered underground.

FutureGen is likely to begin operation in about 2015 and testing it will last for three to five years. If successful, it could run for 60 years. If successful, it will no doubt be duplicated many times over bringing the U.S. ever closer to a hydrogen economy.

How FutureGen will work

FutureGen will be an Integrated Gasification Combined-Cycle (IGCC) electricity plant. In this kind of plant, coal is chemically altered to produce a synthesis gas called syngas. Put another way, gasification occurs when coal is exposed to steam and oxygen at very high temperatures. The resulting syngas, which is about 33% hydrogen, is then segmented so that the hydrogen goes to a hydrogen purification unit. The carbon is removed for sequestration underground, or possibly pumped into oil fields to get more oil out of the ground.

All electricity will be produced after carbon sequestration, meaning there will be zero emissions. The hydrogen used for electricity production will need no further treatment because electricity generation does not need pure hydrogen gas. That hydrogen designated for transportation or other such fuel uses will be further purified.

Possible Uses for the Hydrogen beyond Electricity

FutureGen will establish whether coal-to-hydrogen can produce electricity in a cost-effective, emission-free way and thus serve to subsidize the production of pure hydrogen for other fuel uses.

As discussed, hydrogen is used as a feedstock material for a variety of chemical manufacturing processes. Nationally, between two-thirds and three-quarters of all hydrogen use is for manufacturing fertilizer. Hydrogen is combined with nitrogen to come up with NH3 (anhydrous ammonia), a basic material used in making fertilizer.

At the moment, 65% to 90% of fertilizer is made with natural gas. And because natural gas prices have at least tripled in the past five years, fertilizer production has declined significantly, leaving farmers and others desperate for supply.

Storage and Distribution

Lightweight, fiber-wrapped tanks have been developed and tested for higher-pressure hydrogen storage and generally, storage tanks that are many times stronger than say, a conventional car gasoline tank, are already being manufactured. Alternative solid-state storage systems using alanates and carbon nanotubes are also under development.

At the moment, there are limited hydrogen pipeline networks in the U.S. Some hydrogen tanker trucks are on the road, but eventually, for a true hydrogen economy, rail, air and barge delivery will have to be contemplated and made viable.

Hydrogen as a Transportation Fuel

Perhaps no area of the economy seems more vulnerable to energy price shocks than transportation fuel costs. That's because transportation costs not only affect consumers directly at the gasoline pump, but indirectly through the ripple effect on the higher costs of goods and services at every stage of manufacture, delivery and distribution. This is all quite aside from the environmental impact of using oil and gasoline and the immense question of security and reliability.

Therefore, fundamental to a hydrogen economy is the use of hydrogen as a transportation fuel. Is it possible?

Many knowledgeable people have pointed out the difficulties, not the least of which is distribution to a scale as small as the tank on an individual vehicle. These considerations must be taken seriously. The National Academy of Sciences has pointed out at least four technological and economic challenges to realizing hydrogen as a transportation fuel.

First, cost-effective, durable, safe and environmentally sound fuel cell systems must be developed.

Second, the development of a light-duty vehicle user infrastructure.

Third, reduction of the costs of hydrogen production over time.

Fourth, the sequestering of carbon dioxide of hydrogen production from coal.

Futuregen will begin to address each of these, but many years of purposeful experience will be needed to fully satisfy these concerns.

President Bush has taken the first step down this long road by announcing a $1.2 billion Freedom Fuel Initiative. This initiative seeks to develop the technology needed for commercially viable hydrogen-powered fuel cells that will be key for the storage and distribution challenges cited above.

In combination with the FreedomCAR (Cooperative Automotive Research) Initiative, mass production of safe and affordable hydrogen-powered fuel cell vehicles is contemplated.

The purpose of this research is to close the gap on the current facts:

- Hydrogen is currently four times as expensive to produce as gasoline.
- Current hydrogen storage systems are inadequate for use in the range of vehicles people own.
- Currently, fuel cells are ten time more expensive than internal combustion engines.

If these problems can be overcome, America's greenhouse gas emissions from transportation alone could be reduced by more than 500 metric tons of carbon equivalent each year by 2040. When burned in an engine, hydrogen produces effectively zero emissions. In addition, hydrogen internal combustion engines are about 25% more efficient than their gasoline counterparts and fuel cells are 2 to 3 times as efficient.

Hydrogen powered buses are now being used in California.

If just 1% of the produced syngas from a 500 MW IGCC plant is used to produce hydrogen, that is sufficient hydrogen to provide the fuel needs of 10,000 vehicles. This corresponds to 4 filling stations each with 12 pumps and 350 fill-ups per day.